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TEACHER'S EDITION



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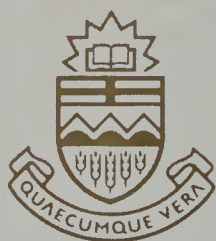
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BIOLOGY

TEACHER'S EDITION

William L. Smallwood

Peter Alexander, Ph.D.

SILVER BURDETT COMPANY
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TEACHER'S CONTENTS

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Revolutions in science are sometimes thought to have little effect on the human race, particularly as compared to political/social revolutions that mark important points in human history. Yet, the nineteenth- and twentieth-century revolutions in physics have led to developments in electronics that are influencing life in nearly all nations of the world. Similarly, revolutions in chemistry, particularly organic chemistry, have helped shape the life-styles of much of the world's population. In biology, advances in disease control and prevention have certainly been an important factor in the lives of millions of people. Today, another revolution in biology is beginning, and its effects may be more widespread and controversial than previous scientific revolutions. Recombinant DNA research, cloning, artificial body parts, brain chemistry and its relationship to mental illness, and pheromones in insect control are some examples of the new ideas and practices that the world's people may soon have to deal with. Who will be able to understand and evaluate new developments in biology? People who are informed in science, who have at least a basic knowledge in biology, will be able to comprehend these new developments and their possible implications. The reactions and decisions of informed people may influence the lives of others.

If biology has been important in school curriculums up until now, particularly as a means of developing appreciation for the living world, it now has perhaps an increased importance. Even for those who will not enter careers in the biological sciences, the subject has a practical value in that it prepares a person for a world in which biological developments can influence everyone's life.

Silver Burdett's BIOLOGY is a comprehensive text designed to give students a well-rounded background in key areas of biology. The development is logical, based on an understanding of life on a cellular-molecular level and proceeding to more complex life forms from unicellular ones. The approach to the diversity of the living world is phylogenetic, thus allowing students to grasp organisms as "whole," with all systems functioning together to support the organism. Individual units on human physiology and ecology are included. These areas are of interest to students. In addition, knowledge in these areas can lead to more healthful personal living and a more appreciative attitude toward the world's living communities.

Finally, this text is a beginning but not an ending. The knowledge and interest developed by students in the science of biology should serve as an incentive, as they grow, to keep themselves informed of biological developments.

INDIVIDUALIZING THE PROGRAM

Silver Burdett's BIOLOGY has been designed to be a complete program, able to meet the needs of biology classes throughout the country. Since the abilities and interests of students will vary, however, teachers can modify the program to suit the particular needs of their classes by emphasizing certain topics, giving less attention to others, or assigning additional material for investigation as necessary. The following guide divides the program into three sections: 1. CORE—includes material that provides a very basic course in biology; 2. AVERAGE—includes the Core plus additional material, making the program suitable for classes of average abilities and interests; 3. ADVANCED—includes all material covered in the program for average classes plus additional material to make the program challenging to above-average classes. While this breakdown can be useful in planning a course, it is only a guide, and each teacher will find sufficient flexibility in the program to design the course needed for his or her particular situation.

	<i>Core</i>	<i>Average</i>	<i>Advanced</i>
Topics	The following chapters: 1. Introduction to Biology; 2. Cell Structure; 6. Cell Reproduction; 12. Classification of Life; 19. The Bryophytes; 20. Seedless Vascular Plants; 21. The Seed Plants; 25. Sponges and Coelenterates; 26. Worms; 27. Mollusks and Echinoderms; 28. Arthropods; 29. Fishes and Amphibians; 30. The Reptiles; 31. The Birds; 32. The Mammals; 40. Tobacco, Alcohol, and Drugs; 41. Population, Community, and Ecosystem; 42. Patterns of Dependency	In addition to the Core, the following chapters should be emphasized: 7. Cellular Traffic; 8. How Traits Are Inherited; 9. Human Genetics; 10. Natural Selection; 11. Early Humans; 13. Viruses; 14. Monera; 15. The Protists; 16. Algae and Fungi; 17. People versus Microbes; 18. Microbes Work for People; 22. Seed Plant Development; 23. Hormones and Plant Responses; 33. Food and Digestion; 34. Blood and Circulation; 35. Respiration and Excretion; 36. The Endocrine System; 38. Skeletal and Muscular Systems; 39. The Reproductive System; 43. Cycles in the Biosphere; 44. Ecological Succession; 47. The Terrestrial Habitat. Some emphasis on 3. Molecules; 4. DNA and Protein Synthesis; 5. Energy in the Cell; 48. People and the Ecosphere	In addition to the Core and Average material, the following chapters should be emphasized: 3. Molecules; 4. DNA and Protein Synthesis; 5. Energy in the Cell; 24. Transport in Plants; 45. The Freshwater Habitat; 46. The Marine Habitat; 48. People and the Ecosphere. Appendix 2, "Cellular Respiration," should also be assigned. Individual outside readings in such topics as recombinant DNA research and immunology should be pursued with periodic reports by students to the class.
	<i>Core</i>	<i>Average</i>	<i>Advanced</i>
Written Assignments	Check Your Facts and selected Review Questions	Check Your Facts and Review Questions	Check Your Facts, Review Questions, and Analysis and Application
Laboratory Investigations in Biology	Investigations 1–6, 15, 25, 33–34, 41–50, 58–60.	All investigations are appropriate—should coincide with topics emphasized in class.	All investigations plus For Further Investigation suggestions from the Record Book.

SCOPE AND SEQUENCE

UNIT I CELL STRUCTURE AND FUNCTION

- Chapter 1 Introduction to Biology**
Biology, Its Branches and Levels of Study
The Methods of the Biologist
- Chapter 2 Cell Structure**
The Cell Theory
General Cell Structure
A Modern View of Cells
- Chapter 3 Molecules**
What Are Molecules?
Water
Carbohydrates
Fats
Proteins
- Chapter 4 DNA and Protein Synthesis**
Structure of DNA
Translating the Genetic Code
Protein Synthesis
Genes and Mutations
- Chapter 5 Energy in the Cell**
Metabolism, Enzymes, and ATP
Photosynthesis
Respiration
- Chapter 6 Cell Reproduction**
The Cell Cycle
Mitosis
Meiosis
- Chapter 7 Cellular Traffic**
Movement of Liquids
Diffusion Through Membranes
Other Forms of Cell Transport

UNIT II CONTINUITY OF LIFE

- Chapter 8 How Traits Are Inherited**
Mendel's Early Experiments

More Experiments—Dihybrids
Other Genetic Discoveries

Chapter 9 Human Genetics
Patterns of Inheritance
Recessive Genes and Genetic Disease
Genes and Blood Groups
Chromosomes and Heredity

Chapter 10 Natural Selection
The Concept of Natural Selection
Darwin and the Theory of Evolution

Chapter 11 Early Humans
Early Human Ancestors
Homo erectus
Neanderthals and Cro-Magnons

Chapter 12 Classification of Life
The Need for and Basis of Classification
The Major Taxonomic Categories
Taxonomic Problems

UNIT III MICROBIOLOGY

Chapter 13 Viruses
The Nature of Viruses
The Activities of Viruses

Chapter 14 Monera
The Nature of Procaryotes
Bacteria
Blue-Green Algae

Chapter 15 The Protists
Protozoa: The Animallike Protists
The Plantlike Protists

Chapter 16 Algae and Fungi
The Higher Algae
The Fungi
Lichens

Chapter 17 People versus Microbes

Microbes and Disease
Defense Against Disease

Chapter 18 Microbes Work for People

Usefulness of Microbes in Nature
Microbes in the Food and Beverage Industry
Microbes in Manufacturing and Sewage Treatment

UNIT IV PLANTS

Chapter 19 The Bryophytes

General Characteristics and Habitat
The Mosses
The Liverworts

Chapter 20 Seedless Vascular Plants

The Horsetails
The Lycopods
The Ferns

Chapter 21 The Seed Plants

The Success of the Seed Plants
The Gymnosperms
The Flowering Plants

Chapter 22 Seed Plant Development

The Plant Embryo and Germination
Plant Tissues and Primary Growth
Secondary Growth

Chapter 23 Hormones and Plant Responses

Plant Hormones
Responses to the Environment

Chapter 24 Transport in Plants

The Flow of Water in Vascular Plants
The Movement of Food in Vascular Plants

UNIT V ANIMALS WITHOUT BACKBONES

Chapter 25 The Simplest Animals

General Characteristics of Animals
Phylum Porifera
Phylum Coelenterata

- Chapter 26 Worms**
Phylum Platyhelminthes
Phylum Nematoda
Phylum Annelida
- Chapter 27 Mollusks and Echinoderms**
Phylum Mollusca
Phylum Echinodermata
- Chapter 28 The Arthropods**
General Characteristics of Arthropods
The Arachnids
The Crustaceans
The Insects

UNIT VI ANIMALS WITH BACKBONES

- Chapter 29 Fishes and Amphibians**
The Fishes
The Amphibians
- Chapter 30 The Reptiles**
General Characteristics of Reptiles
The Orders of Living Reptiles
- Chapter 31 The Birds**
General Characteristics of Birds
The Body Plan of Birds
Bird Flight and Migration
- Chapter 32 The Mammals**
Characteristics of Mammals
Important Orders of Mammals
Special Adaptations of Mammals

UNIT VII HUMAN PHYSIOLOGY

- Chapter 33 Food and Digestion**
The Digestive Process and Early Stages in Digestion
The Role of the Stomach
The Small and Large Intestines
Human Food Needs

- Chapter 34 Blood and Circulation**
The Composition and Functions of Blood
Heart and Blood Vessels
Systemic, Pulmonary, and Lymphatic Pathways
- Chapter 35 Respiration and Excretion**
Structure and Function of the Respiratory System
Structure and Function of the Excretory System
- Chapter 36 The Endocrine System**
The Nature of Hormones
Endocrine Glands, Their Hormones and Effects
- Chapter 37 Nerves and the Brain**
Neurons and Nerves
Organization of the Nervous System
Structure and Functions of the Brain
Receptors and the Senses
- Chapter 38 Skeletal and Muscular Systems**
Cartilage and Bone
Structure and Functions of the Skeletal System
Structure of the Muscular System
Muscle Action
- Chapter 39 The Reproductive System**
The Male and Female Reproductive Systems
The Menstrual Cycle, Pregnancy, and Birth
- Chapter 40 Drugs, Alcohol, and Tobacco**
The Use and Abuse of Drugs
The Use and Abuse of Alcohol
The Use and Misuse of Tobacco

UNIT VIII ECOLOGY

- Chapter 41 Population, Community, & Ecosystem**
Population and Habitat
Community and Ecosystem
Producers, Consumers, and Decomposers
- Chapter 42 Patterns of Dependency**
The Flow of Energy in the Community
Food Chains and Webs
Types of Symbiotic Relationships

Chapter 43 Ecological Cycles

The Oxygen Cycle
The Carbon Cycle
The Nitrogen Cycle
The Phosphorus Cycle

Chapter 44 Ecological Succession

The Competitive Exclusion Principle
Primary Succession
Secondary Succession

Chapter 45 The Freshwater Habitat

Limiting Factors in Freshwater Habitats
Ecological Classification of Freshwater Organisms
The Lentic Community
The Lotic Community

Chapter 46 The Marine Habitat

Ecological Classification of Organisms
in the Marine Habitat
Zones in the Marine Habitat
Energy Flow in the Marine Community
Unique Marine Communities—Coral Reefs and Estuaries

Chapter 47 The Terrestrial Habitat

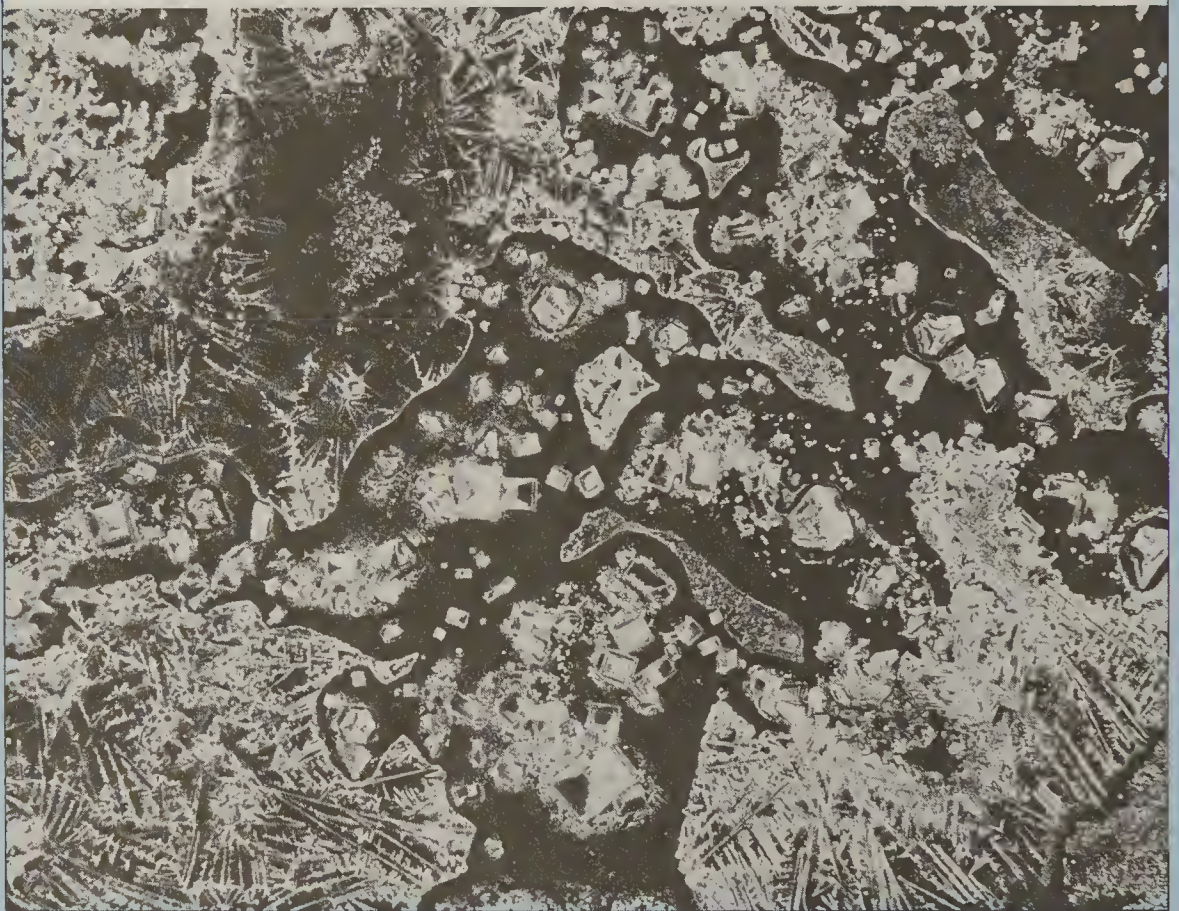
Limiting Factors in the Terrestrial Habitat
The Tundra
The Taiga
Moist Temperate Coniferous Forest
Temperate Deciduous Forest
Temperate Grasslands
Tropical Savannas
Tropical Rain Forests
Deserts

Chapter 48 People and the Ecosphere

Human Population Growth
Problems Caused by Population Growth
Limiting Factors and Population Growth

Investigation 7 from *Laboratory Investigations in Biology* can be done with this chapter.

3 *Molecules*



FEATURES OF THE TEXT

The Teacher's Edition of BIOLOGY has been designed to aid you in teaching the course. A set of **OBJECTIVES** appears at the beginning of each chapter. These indicate the important points that are covered in the chapter and that students are expected to learn. Laboratory investigations appropriate for the particular chapter being studied are also referenced for the teacher on the chapter opening spread where applicable.

OBJECTIVES

- To explain basic atomic and molecular structure
- To understand the basic nature of the covalent and ionic bonds
- To understand water's unique properties of polarity
- To know the basic structure of carbohydrates
- To understand the basic structure of the typical fat molecule
- To know that proteins are made up of 20 different amino acids arranged in chains

What Are Molecules?

3-1 Molecules make up living matter Can you imagine what a cell organelle would look like if it were magnified 5 million times? Suppose, for example, that an organelle like the chloroplast could be made as large as a football and you could hold it in your hand. What would you see when you observed this organelle? You would see **molecules**. Molecules are the subunits that make up organelles. Molecules are the building blocks that make up *all living matter*.

3-2 Molecules are made up of subunits Now imagine a molecule from an organelle enlarged several million times. What would you see now? You would see **atoms**, which are the subunits that make up all molecules. Atoms are the basic building blocks of *all matter*.

3-3 The simplest atom Only 92 different kinds of atoms have been found throughout the universe. (Another 11 have been created in minute quantities in the laboratory.) The simplest atom is the hydrogen atom. The central part of the hydrogen atom, called the **nucleus**, has just one particle. This particle is called a **proton** (prō'ton). The proton is a particle with a positive electrical charge.

Another particle, called an **electron** (i lek'tron), is in orbit around the hydrogen nucleus. The electron has a negative electrical charge. With 1 electron and 1 proton, the electrical charges are balanced. Thus the hydrogen atom itself has no electrical charge. It is said to be *neutral*.

MAIN IDEA

Molecules are the subunits that make up all organelles.

SCIENCE BACKGROUND

It is recommended that ball-and-stick models be used whenever any molecule is discussed.

MAIN IDEA

Molecules are made up of atoms, which are the building blocks of matter throughout the universe.

MAIN IDEA

There are 92 different atoms found in nature. The simplest atom, hydrogen, has one positively charged particle called a proton in its nucleus and one negatively charged particle called an electron that orbits around the nucleus.

Each chapter is divided into sections corresponding to major topics covered in the chapter. Each section is further divided into numbered subsections dealing with specific concepts. A **MAIN IDEA** briefly states the concept for each subsection. In addition, **SCIENCE BACKGROUND** notes occur throughout the chapter. These provide additional information on the topics being discussed, allowing for a more effective teaching presentation.

SCIENCE TERMS

proteins
amino acids
glycine
alanine
lysine
cysteine
primary structure
peptide bond
polypeptide chain
denatured
hemoglobin

MAIN IDEA

Proteins are formed by the assembly of amino acids in a specifically designated order.

ANSWERS TO CHECK YOUR FACTS

1. Nitrogen.
2. Proteins are made of amino acid subunits.
3. Protein molecules are extremely large and complex.
4. The part of an amino acid that is unique to that type of amino acid.
5. A covalent bond between amino acids.
6. Between R groups.
7. A protein whose three-dimensional structure has been permanently changed.
8. The primary structures of the polypeptide chains in the molecule.
9. A different amino acid in sequence will cause different bonding patterns and thus a different shape.

ANSWERS TO REVIEW QUESTIONS

1. Carbon, oxygen, hydrogen, and nitrogen.
2. Ions have more or fewer electrons than their atomic number and thus are charged.

Their studies showed that the primary structure of the alpha chains in the two hemoglobins was exactly the same. But in the beta chains there was one very small difference. In normal hemoglobin, position number six of the beta chain has an amino acid called glutamic acid. The beta chain of abnormal hemoglobin has the amino acid valine in the sixth position.

In the case of hemoglobin just 2 different amino acids out of 600 are enough to change the three-dimensional shape of the molecule. In turn this can cause some red blood cells to become sickle-shaped. Such cells can plug small blood vessels like a log jam in a river. This prevents normal blood cells from carrying oxygen.

3-26 How do the right amino acids get lined up? There are 100,000 or more different proteins in the cells of most plants and animals. The typical protein probably averages well over 1,000 amino acids in all its chains. We have seen, with the example of sickle-cell anemia, the extreme importance of primary structure in the overall shape and function of a protein. These facts lead us to an important question. How can a cell, which builds all the different proteins, line up the millions of amino acids in the right order so that each protein will function properly? To do so a cell would need something like a book of instructions that would list the primary structure for each protein. Also the cell would need some kind of precision assembly plant where all the amino acids would be linked together according to the instructions for each protein.

Where in the cell is the "book of instructions"? And where is the "assembly plant"? These questions will be answered in the next chapter.

CHECK YOUR FACTS

1. What element is not found in fats or carbohydrates but is found in proteins?
2. How are proteins and amino acids related?
3. Why has the protein molecule been so difficult to analyze and understand?
4. What is meant by the term *R group*?
5. What is a peptide bond?
6. Where are ionic bonds found in polypeptides?
7. What is a denatured protein?
8. What determines the shape of a protein molecule?
9. Why can a single change in the primary structure affect the function of the protein?

Each major section in a chapter contains a list of **SCIENCE TERMS** for the student. A set of questions, **CHECK YOUR FACTS**, concludes each major section.

At the end of each chapter, a concise **SUMMARY** allows students to review the important points covered in the Chapter. A set of **REVIEW QUESTIONS** tests student knowledge of concepts covered throughout the chapter. In addition, **ANALYSIS AND APPLICATION** questions chal-

SUMMARY

Matter is made up of particles called atoms. There are 92 naturally occurring types of atoms or elements. Of these 92, the four elements carbon, oxygen, nitrogen, and hydrogen make up nearly all living matter. Atoms bond with each other in various ways to form molecules.

Water is the most abundant inorganic molecule found in living matter. Because of the bonding arrangement within the water molecule, it has polar characteristics. This polarity enables water to act as an excellent solvent.

Carbohydrates are a group of organic molecules that are important in energy storage and structural support. The structural subunits of carbohydrates are the simple sugars, such as glucose and fructose.

Fats store energy more efficiently than carbohydrates, a fact that makes fats much more vital to mobile animals than to plants.

REVIEW QUESTIONS

1. What are the four most common elements found in living matter?
2. Explain the difference between ions and isotopes.
3. Describe ionic, covalent, peptide, and hydrogen bonding. Which is weakest?
4. How do elements differ from compounds?
5. Why can water act as a good solvent?
6. What are the subunits of polysaccharides? Of polypeptides? Of fats?
7. Describe dehydration synthesis.
8. What are some differences in the carbohydrate and fat composition of plants compared with that of animals?
9. How many amino acids are there, and how do they differ in structure?
10. Sickle-cell anemia is caused by a protein with an abnormal primary structure. Explain.

ANALYSIS AND APPLICATION

1. As heat is applied to a protein, denaturing starts to occur. What type of bonds are probably being broken? Explain.
2. The mass number of an atom is 67 and it contains 37 neutrons. A second atom has 31 electrons and a mass number of 66. Both atoms are of the same element. What is their atomic number? How can they possibly be the same element?

Isotopes of an element have varying amounts of neutrons and different atomic masses

3. Ionic bonding is an attraction between oppositely charged ions. Covalent bonding is a sharing of electrons between atoms. A peptide bond is a covalent bond between amino acids. Hydrogen bonds form between polar molecules. Hydrogen bonds are weakest.

4. An element contains only one type of atom. Compounds contain two or more types of atoms.

5. Water is a polar liquid

6. Monosaccharides, or single sugars. Amino acids. Glycerol and fatty acids.

7. An OH group from one molecule combines with an H from another to form one water molecule and a covalent bond between the two molecules

8. Plants contain starch and cellulose but not glycogen. The fats in plants are generally unsaturated. The opposite holds true for animals.

9. Twenty. They each have a unique R group.

10. A change in the amino acid sequence, or primary structure, causes hemoglobin to change its shape. This reduces the molecule's ability to function properly

ANSWERS TO ANALYSIS AND APPLICATION

1. The hydrogen bonds between the amino and acid groups will be easiest to break.
2. Thirty. The first atom must have 30 protons ($67 - 37 = 30$). The second atom has one less neutron and one more electron. It has to be another isotope and it must be a negative ion.

lenge students' abilities in interpreting situations in the light of topics covered in the chapter. Finally, answers to all questions appear in the margins of the Teacher's Edition.

SILVER BURDETT BIOLOGY PROGRAM

BIOLOGY and Teacher's Edition

William L. Smallwood

Peter Alexander

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in BIOLOGY**

Anne Fleishel Harris

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The Continuity of Life

Adapt, Migrate, or Die

Classifying Life

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BIOLOGY



CANADIAN METRIC EDITION



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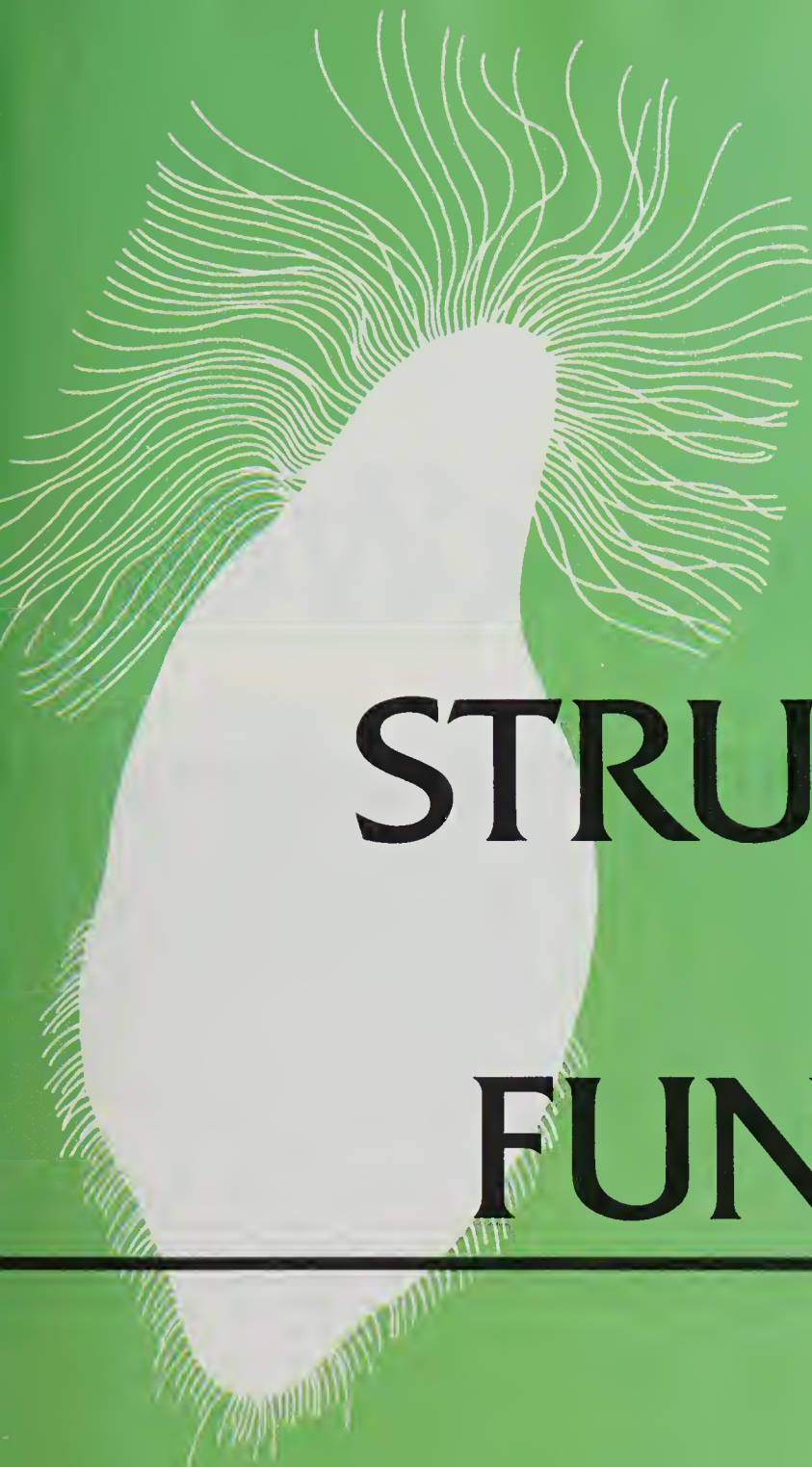
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Unit 1

CELL STRUCTURE AND FUNCTION

This unit is about cells, which are the fundamental living units of all organisms. Cells are the structural building blocks, like bricks of a building. Cells are the units within which all functions occur or originate.

Our brains think and our muscles move, but it is the brain cells and the muscle cells that actually carry out the functions. The study of cells is the first order of business in any logical study of biology. An understanding of cells makes it possible to understand all aspects of life in all the different organisms.

Investigations 1–3 from *Laboratory Investigations in Biology* can be done with this chapter.

1 Introduction



OBJECTIVES

- To define *biology*
 - To define an organism
 - To list the major branches of biology
 - To understand how life is organized into a hierarchy of levels
- To define *organelle, cell, tissue, organ, system, population, community, ecosystem, biosphere, and ecosphere*
 - To explain that life and death can occur independently at many different levels of organization

to Biology

1-1 Biology defined Biology is one of the specialized fields of science. The name comes from two Greek words—*bios*, which means “life,” and *logos*, which means “speech” or “reason.” **Biology** (bī ol’ə jē) is the science of life and life processes.

1-2 The major branches of biology There are well over a million different living things on the planet Earth. Each individual living thing is called an **organism** (or’gə niz əm). Each organism is complex and so are the differences between organisms. Therefore there are many specialized branches within the field of biology.

The major branches of biology are botany and zoology. **Botany** (bot’ə nē) is the study of plants. **Zoology** (zō ol’ə jē) is the study of animals. Before the use of microscopes, all organisms were thought to be either plants or animals. Now we recognize a third major branch of biology, which is devoted to the study of small organisms called **microorganisms** (mī krō ôr’gə niz əmz). Microorganisms can only be studied with the aid of a microscope. The branch of biology that deals especially with microorganisms is called **microbiology** (mī krō bī ol’ə jē).

1-3 Structure and function While studying organisms, biologists have always had two basic goals. These have resulted in two specialized fields of biological study.

The first goal was to understand how organisms are put together, or made. The pursuit of this goal developed into the specialized field of **anatomy** (ə nat’ə mē). Anatomy is the study of the structure of organisms and their parts.

MAIN IDEA

Biology is the science of life and life processes.

William Harvey demonstrating the flow of blood in a deer to Charles I.



SCIENCE BACKGROUND

Logos is commonly translated into the English term *dis-course*, which would not be understood by many students.

SCIENCE BACKGROUND

Microbe is another term often used instead of *microorganism*; however, in the past, *microbe* has most often been used to describe bacteria, especially pathogenic types.

SCIENCE BACKGROUND

Anatomy is often restricted to the study of human structure and the structure of higher animals. *Morphology* is a broader, though less commonly used, term that refers to the study of structure.

MAIN IDEA

The biologist's pursuit of knowledge of the structure and function of organisms has led to the development of the special fields of anatomy and physiology.

MAIN IDEA

Life is uniquely organized into a hierarchy of levels of organization. Within the individual the levels are, in order of increasing complexity, the atom, molecule, organelle, cell, tissue, organ, and system.

SCIENCE BACKGROUND

Many biologists use the term *levels of integration* in place of *levels of organization*.



FIGURE 1-1 The levels of organization of life

The second goal was to understand how organisms and their parts work, or function. Biologists pursuing this goal developed the specialized field of **physiology** (fiz ē ol'ə jē). Physiology is the study of the functions of organisms.

1-4 Levels of organization One of the most important characteristics of life is its unique organization. Life is organized in a hierarchy, which is a series of levels of increasing complexity. This hierarchy of life is made up of **levels of organization**.

We can explain the unique organization of life by starting near the bottom of the hierarchy. All organisms, with few exceptions, are made up of cells. The **cell** (sel) is the smallest subunit of organisms that can exist independently and carry out all basic life functions. However, there are three levels of organization below the level of the cell. The cell itself is made up of **organelles** (ôr gə nelz'), which are structures that carry out specialized functions in the cell. In turn, organelles are made up of **molecules**, and molecules are made up of **atoms**. These sublevels of cellular organization are discussed in Chapters 2 and 3.

Above the level of the cell is the **tissue** (tish'ü), which is a group of cells that works as a team and carries on one or more specialized functions. An example is the tissue that lines and protects the inside of your mouth. Most organisms have tissues.

Above the tissue level is the **organ** (ôr'gən), which is made up of two or more tissues. An organ is a specialized structure, such as the heart or stomach, that has a specific function or functions.

At a high level, mainly in animals, there is a level of organization called the organ-system, or simply, **system** (sis'təm). The system is a group of organs that work together to perform one or more specific functions. An example is the digestive system, which includes the stomach and several other organs that function together to digest food.

1-5 Beyond the individual The individual organism, or individual, is near the middle of the hierarchy. This position is the result of a change in the thinking of biologists from the last century, when the individual was considered as the top level of organization. The modern biologist thinks of the individual as a temporary unit of life. Actually most individuals live for just days, weeks, or months.

The truly stable and long-lived unit of life is the **population** (pop yə lā'shən), which is the level of organization beyond the level of the individual. A population is a group of individuals of the same kind, usually defined by space and time. For example, a population could be all the wild bison in Wood Buffalo Park in Alberta in September. Like individuals, populations live and die. Most live for millions of years. When they die, they become **extinct**.

SCIENCE BACKGROUND

If biologists studied only the inside of the blue whale's body and knew the structure and function of every cell and organelle, they would never know why the world population of blue whales is vanishing.

This example is a bit facetious, but it is a good one to help students appreciate the fact that the answers to biological problems are not always found by looking inside the bodies of organisms. To solve many biological problems, the researcher must look beyond the level of the individual to other populations (in the blue whale's case, to the human population, particularly in Japan), and to the physical environment.

MAIN IDEA

The level of organization above the individual is the population, which is a much more long-lived entity within the realm of life.

A herd of bison is an example of a population.



MAIN IDEA

The community is a group of populations living within an area. An ecosystem is a community and the physical environment with which it interacts.

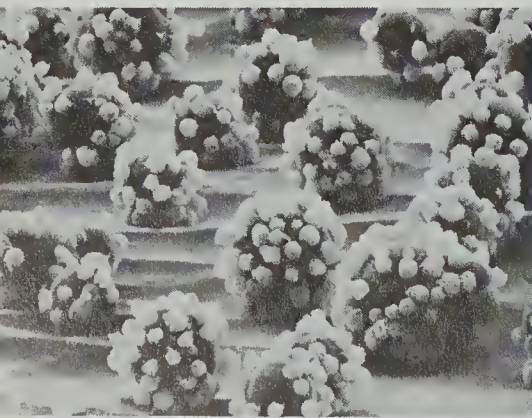
MAIN IDEA

The biosphere is the total sphere of life and the largest community. The ecosphere is the largest ecosystem.

SCIENCE BACKGROUND

HeLa cells were taken from a woman named Henrietta Lacks in February 1951. They were cervical cancer cells that have been remarkably viable in laboratory cultures and have been widely used for culturing viruses.

The photograph below shows HeLa cells. These are cancer cells taken from a person who died in 1951. These cells are used in many research labs.



1–6 Community and ecosystem The next higher level of organization is the **community** (kə myü'nə tē), which is a group of populations living in an area. An example is a pond community, which includes all the populations living in or near a pond.

It is impossible to understand the workings of a community without considering the physical environment with which it interacts. For example, a pond community is constantly affected by the nature of the water in the pond, the chemicals dissolved in it, and weather conditions above it. Thus biologists now link the community and the physical environment with which it interacts into one single unit, or level of organization. Such a unit is called an **ecosystem** (ē'kə sis təm). The specialized study of organisms and their environment—including populations, communities, and ecosystems—is called **ecology** (ē kol'ə jē).

1–7 Biosphere and ecosphere It is sometimes useful to think of the sum total of all life on the earth as a single unit, or level of organization. Such a unit, called the **biosphere** (bī'ə sfir), is often used to describe the entire sphere of life that is the living portion of our earth. An even broader unit is sometimes considered to be the highest level of organization. This is called the **ecosphere** (ē'kə sfir) and includes all life on the earth and the physical environment that interacts with all life. The ecosphere is the largest ecosystem.

1–8 Life and death Life and death can occur at several levels of organization. Within an individual, such as the human being, thousands of cells are dying every hour. Death can occur to tissues and organs while the human being still lives.

On the other hand, a human can die and yet cells, tissues, and even organs from that person can continue to live for many years. Cells from a person who died in 1951 are still alive in laboratory cultures throughout the world. Organs, such as kidneys, from dead persons continue to function in persons that live normal lives.

We have already mentioned that death, or extinction, can occur to a population. In fact, that is the normal fate of populations, although it usually takes millions of years for extinction to occur. Death also occurs to communities. Lake and pond communities die naturally when their water basins are filled with soil that is washed from hills and mountains. Many wetland communities have died after they have been drained and covered with houses, highways, and shopping centers. Even death of much of the



Direct observation is one of the biologist's methods.

largest community, the biosphere, is not out of the question if a nuclear war should spread deadly radiation over the world.

1–9 The biologist's method: direct observation Many biologists perform research to try to discover new facts about life. Their methods are similar to the methods of scientists in other fields. One method of research, used more often by biologists than by other scientists, is direct observation. For example, a biologist in the rain forest of the Amazon Valley in South America might discover a new kind of bird. Many facts about that bird would be unknown. What does it eat? What kind of nest does it build? What is the average number of eggs that are laid and what percent are likely to hatch and grow to adulthood? The only way for such questions to be answered is for the researcher to directly observe the birds and their activities.

MAIN IDEA

One biological research method involves direct observation of biological phenomena.

MAIN IDEA

Another biological research method involves the experimental approach, the steps of which include stating the problem, researching the literature, and designing and completing the experiment using a control.

SCIENCE BACKGROUND

The announcement and brief description of the Soviet's degassed "wonder water" was published in *Science*, Vol. 202 (October 27, 1978), p. 415. Sugar beets were mentioned in the report. Their root weight increased 40 percent and sugar content 1.5 percent. There is no good hypothesis to explain the effects of the degassed water, but it is speculated that degassed water might be better because its physiochemical properties bear a much closer resemblance to the fluid in cells than does tap water. Experiments with degassed water (made by boiling and cooling water) could be designed by students as worthwhile projects for science fairs.

1–10 The biologist's method: the experimental approach The other method of research, used widely by scientists in other fields, is the experimental approach. In this method biologists use experiments to solve a problem. They may also use this method to confirm the findings of other scientists, an important part of the scientific process.

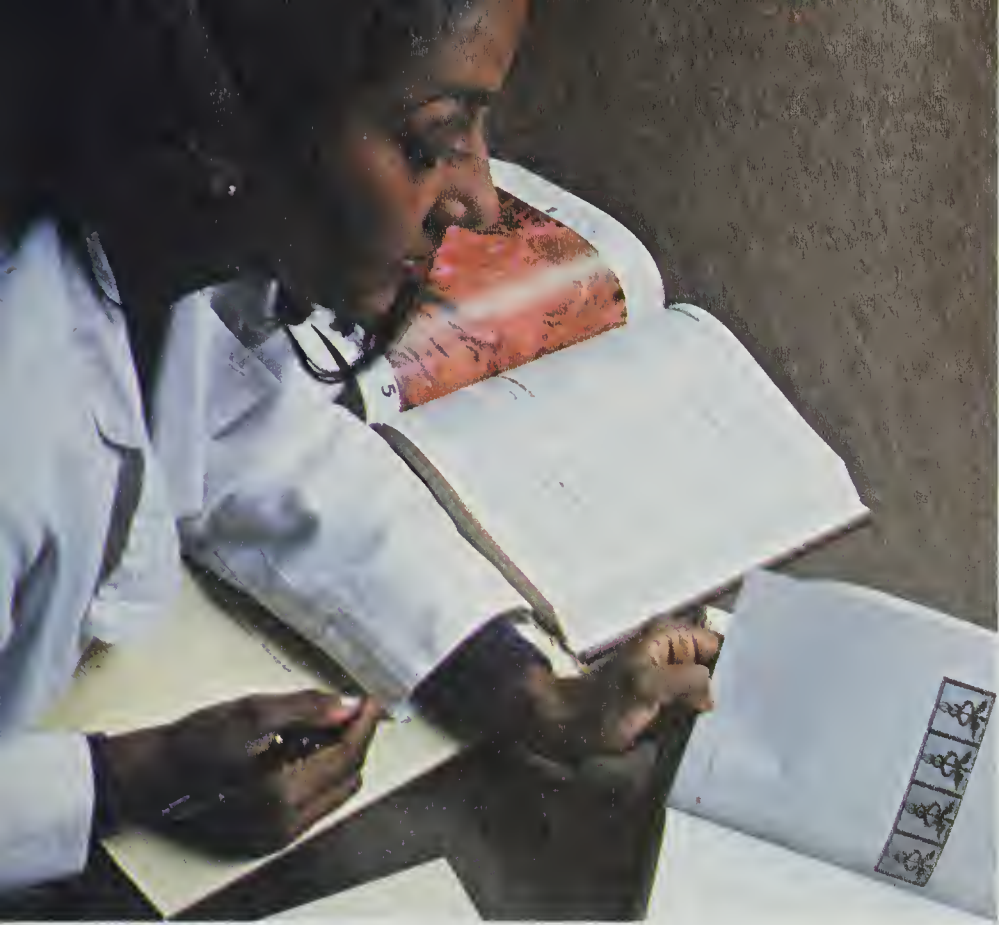
For example, Soviet biologists claim that they have discovered a new way to increase the size and yield of certain plants. They claim that water with dissolved gases removed, called degassed water, causes better plant growth when seeds are soaked in it before planting. Their report noted that cotton plants grown from such seeds yielded from 10 to 12 percent more cotton than plants grown by normal methods. After reading this report, another scientist may wish to confirm the findings of the Russians. By following the basic steps of the experimental method, another scientist would then be able to conduct a similar experiment to prove the results.

The first step is to state the specific problem to be resolved by the experiment. The problem might be stated as follows: What would be the effect on sugar beets if the seeds were soaked in degassed water before they were planted?

The next step would be to read and gather all available information that relates to solving the problem. Sometimes this involves hours of library research, including the study of **journals** (jēr'nəlz), which are specialized magazines that contain research reports. These reports often contain facts necessary for their research.

Another step is to design the experiment, that is, to determine the procedure that will be followed and the materials that will be needed. For this experiment a quantity of degassed water will have to be produced. Also, a length of time for soaking the seeds will have to be determined. The researcher must also include a **control** (kən trōl') in the design of the experiment. This will allow for comparison with the normal process. As a control for this experiment, sugar beet seeds would be soaked in plain water and grown under the same conditions. The sugar beets grown from seeds soaked in degassed water would be the experimental beets. Those grown from seeds soaked in plain water would be the control beets.

The next step is to perform the experiment, treating the experimental and control seeds exactly alike except for the water in which they are soaked. Also during the experiment, careful notes must be taken regarding observations of the experimental and control plants.



Scientific journals contain information that aids the biologist in research.

SCIENCE TERMS

biology	population
organism	extinct
botany	community
zoology	ecosystem
microorganisms	ecology
microbiology	biosphere
anatomy	ecosphere
physiology	journals
levels of	control
organization	hypothesis
cell	verification
tissue	theory
organ	scientific fact
system	

1-11 Analysis of the experiment Let's now leap forward two months and look at the next steps. The biologist must have some characteristic to use for comparison. For sugar beets it might be the average weight of the beet, or it could be the average sugar content of the beet. In either case the results must be carefully measured for both the experimentals and the controls.

The final step in the experiment is to measure the results, analyze them, and draw conclusions. Perhaps the weight of the experimental beets averaged 40 percent heavier than the control beets. Perhaps the average sugar content of the experimental beets was 1.5 percent higher than that of the control beets. After this analysis the biologist could conclude that in this one experiment degassed water increased the average weight of sugar beets by 12 percent, and increased the sugar content by an average of 0.9 percent.

1-12 Hypothesis, verification, and theory Usually, after several such experiments have been carried out, the biologist forms a **hypothesis** (hī poth'ə sis). The hypothesis can be defined as a temporary explanation of observed or experimental results. For example, after performing several experiments with degassed water, a biologist might develop the following hypothesis: Seeds soaked

MAIN IDEA

Another step in the experimental approach is analyzing the results of the experiment.

MAIN IDEA

After analysis of the experiment, hypothesis that would attempt to explain or account for the experimental results might be developed. Following one or more experiments, the results, analysis, and hypothesis may be published, and other biologists are likely to repeat the experiments. After a hypothesis is widely verified, it becomes a theory.

ANSWERS TO REVIEW QUESTIONS

1. Biology is the science of life and life processes. The name originates from the Greek words meaning "life" and "speech" or "reason."
2. An organism is an individual living thing. Example: turtle.
3. Botany is the study of plants; zoology is the study of animals; and microbiology is the study of microorganisms, which do not fit into either of the other categories.
4. Anatomy is the study of structure, while physiology is the study of functions. Both fields include the study of all organisms.
5. *Cell*—the smallest subunit of organisms that can exist independently and carry out all basic life functions. *Organelle*—structure that carries out a specialized function in a cell. *Tissue*—a group of cells that works as a team and carries on one or more specialized functions. *Organ*—a structure made up of two or more tissues that has one or more specific functions. *System*—a group of organs that work together to perform one or more specific functions.
6. Cell, tissue, organ, system, individual, population, community, system, biosphere, ecosphere.
7. A population is a group of individuals of the same kind, usually defined by space and time. Examples will vary.
8. A community is a group of populations living in an area, while the ecosystem includes that community plus the physical environment with which it interacts.
9. Biosphere and ecosphere.
10. At all levels from the organelle up through the ecosphere.
11. The study of levels of

in degassed water before planting result in larger, more productive plants than do seeds that are soaked in ordinary water.

At this time the biologist would probably write a report of the experiment that would include the method of experimentation, the results, the analysis, and the hypothesis. Such a report, called a **paper** (pā' pər), would probably be read at a scientific meeting to persons who do the same kind of research and be published in a journal that specializes in similar kinds of research.

Often, when hearing or reading an interesting research report, a biologist may repeat the same experiment. Others may perform the experiment in different ways. Then all the new experiments are analyzed to see if the hypothesis can be supported, or if it is wrong. This general process of repeating research, called **verification** (ver ə fə kā'shən), often requires several years and the work of many experimenters. For this reason, scientific knowledge is more dependable than any other kind of knowledge. The scientific process must be tested, or verified, over and over by careful scientists.

After much support by verification, the hypothesis gradually fades away. It is replaced by a **theory** (thē'ər ē), which is knowledge that is supported by a large amount of verification and is widely accepted by scientists. The final step is the change from theory to **scientific** (sī ən tif'ik) **fact**. The scientific fact is a true statement that can always be verified. Certain important or well-known scientific facts are often called scientific laws.

SUMMARY

Biology is the study of life and life processes. There are three major fields of biology: botany, zoology, and microbiology. Biologists have always tried to understand the structure and function of organisms. This has led to the development of anatomy and physiology as specialized fields of biology.

Life has a unique organization. It is organized into a hierarchy of levels of organization, beginning with the atom, molecule, organelle, and cell and increasing in complexity. It is possible for both life and death to occur at many different levels of organization.

Biologists do research by direct observation and by the experimental approach. The experimental approach involves basic steps that are followed. The results are always analyzed, and a hypothesis may be developed.

REVIEW QUESTIONS

1. Define *biology* and explain the origin of the term.
2. What is an organism? Give an example.
3. Explain the difference between botany, zoology, and microbiology.
4. How does anatomy differ from physiology? Do both subjects apply to plants, animals, and microorganisms?
5. Define *cell*, *organelle*, *tissue*, *organ*, and *system*.
6. List all levels of organization in the hierarchy of life from the cell to the highest level of organization.
7. Define *population* and give an example.
8. What is the difference between a community and an ecosystem?
9. What is the largest community? What is the largest ecosystem?
10. Death can occur at which of the levels of organization in the hierarchy of life?
11. What is ecology?
12. What term is used to describe the death of a population?
13. Explain what is meant by the direct observation method of biological research.
14. Name and describe the steps involved in the experimental approach to research.
15. Explain how verification helps guarantee the accuracy of scientific information.

ANALYSIS AND APPLICATION

1. A human being dies in an auto wreck, but the dead person's kidneys and corneas (clear covering of the eyes) are transplanted into other persons, where they continue to function. What fact about the organization of life does this illustrate?
2. Degassed water can be prepared by boiling ordinary tap water for about 15 min. Seeds can be caused to grow (germinate) by laying them in paper towels that are soaked with degassed water. Later they can be transplanted in soil. Design an experiment that will determine if degassed water can affect one or more characteristics of a plant.
3. Suppose a person wants to experiment with a highly advertised fuel additive that is supposed to increase the gasoline mileage of automobiles. Suppose that person added the product to gasoline in the tank, then drove the car a certain distance and checked the mileage. Is that enough to test the claims of the advertising? Explain.

organization beyond the level of the individual.

12. Extinction.
13. By this method the biologist observes some organism or process and reports on the observation.
14.
 - a. State the problem.
 - b. Read and gather information that relates to the problem.
 - c. Design the experiment including a control.
 - d. Perform the experiment as accurately as possible while constantly recording notes of observations.
 - e. Analyze the results.
 - f. Develop a hypothesis.
 - g. Write a paper and perhaps read it at a scientific meeting or publish it in a journal.
15. Verification is the process of repeating experiments and observations to see if the results turn out the same for other researchers. Information that is constantly challenged and checked for accuracy is more accurate than information that does not have to undergo such a process.

ANSWERS TO ANALYSIS AND APPLICATION

1. It illustrates the fact that life and death can occur independently at several levels of organization.
2. Answers will vary, but they should include statement of the problem and an experimental design that includes a control.
3. The hope is that the student will see that a control also has to be involved—driving the same distance with no additive in the tank.

Investigations 4–6 from *Laboratory Investigations in Biology* can be done with this chapter.

2 *Cell Structure*



OBJECTIVES

- To appreciate Hooke's role in the evolution of the cell theory
- To understand that organisms are made up of not only cells but also cell products
- To explain Virchow's principle
- To know the structure of a cell
- To understand that multi-nucleate organisms are exceptions to the general cell theory

MAIN IDEA

Robert Hooke named cells after the holes that he observed in microscopic slices of cork.

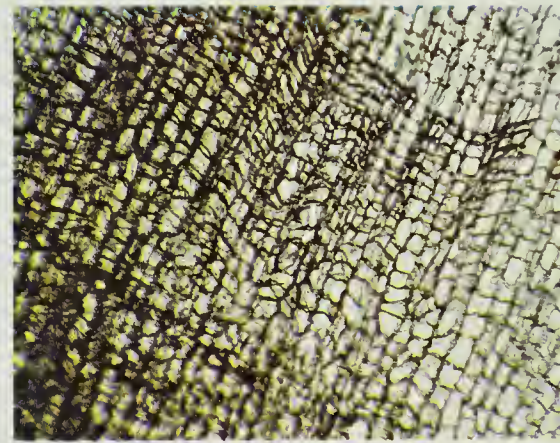
The Cell Theory

2-1 Hooke's cells Robert Hooke was an English scientist. He made several important discoveries in the physical sciences. But Hooke will always be remembered in biology for naming something that he did not see.

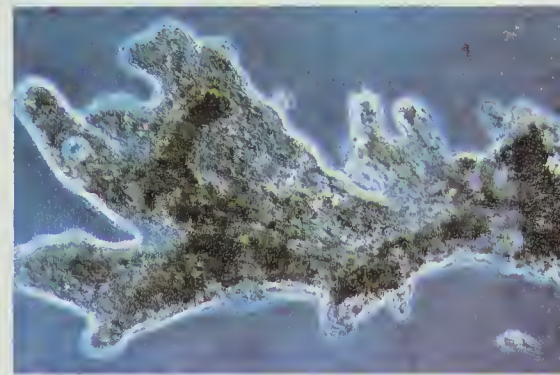
Hooke lived in the 1600s. At that time the microscope was just beginning to be used. It was an instrument often used by hobbyists who liked to look at small things for the fun of it. However, Hooke made careful drawings and wrote descriptions of what he saw. One thing he observed was cork, which he described as being full of holes that looked like little boxes. These "little boxes" reminded him of the small rooms in monasteries where monks lived. Those small rooms were called cells. So *cells* is the name Hooke gave to the empty "little boxes" in the cork.

Cork was once living material on the outside of a tree. The small holes were once living cells. But by the time Hooke observed the cork, the cells had been dead for a long time. Hooke had only observed the holes where living cells had been.

2-2 The cell theory After Hooke many other scientists began to use the microscope. They looked at thin slices of plants and animals. Everywhere, in all plants and animals, they saw small objects that they called cells. Other scientists looked in samples of pond water. They saw the same kinds of small objects. But these were individual organisms with a body made up of one cell. These organisms were called **unicellular** (yü nə sel' yə lər) **organisms**.



Hooke observed that cork is made up of empty little "boxes," which he called cells.



A unicellular organism performs all life functions.

MAIN IDEA

The cell theory has evolved into a scientific fact that all living organisms are made up of cells.

MAIN IDEA

Most organisms are made up of both cells and cell products.

SCIENCE BACKGROUND

One of the main cell products of plants is cellulose, which is a polysaccharide that will be discussed in the next chapter. Collagen, a protein, is an important product of animal cells.

MAIN IDEA

The idea of spontaneous generation, which held that life could originate from nonlife, was finally disproved by Louis Pasteur.

SCIENCE BACKGROUND

Some scientists repeated Pasteur's experiments using hay infusions. They often could not

Cells seemed to be the basic structural units for all forms of life. That idea was stated several times in the early 1800s. But there were doubts among scientists. Could every living thing on the earth be made up of cells? More scientists researched this question and concluded that all plants, all animals—all organisms—are made up of individual units called cells. This idea then became known as the **cell theory**. And today that same idea is known as the cell theory, even though it is no longer a theory. Today we know it to be a fact. All organisms (with exceptions that will be discussed later) are made up of cells.

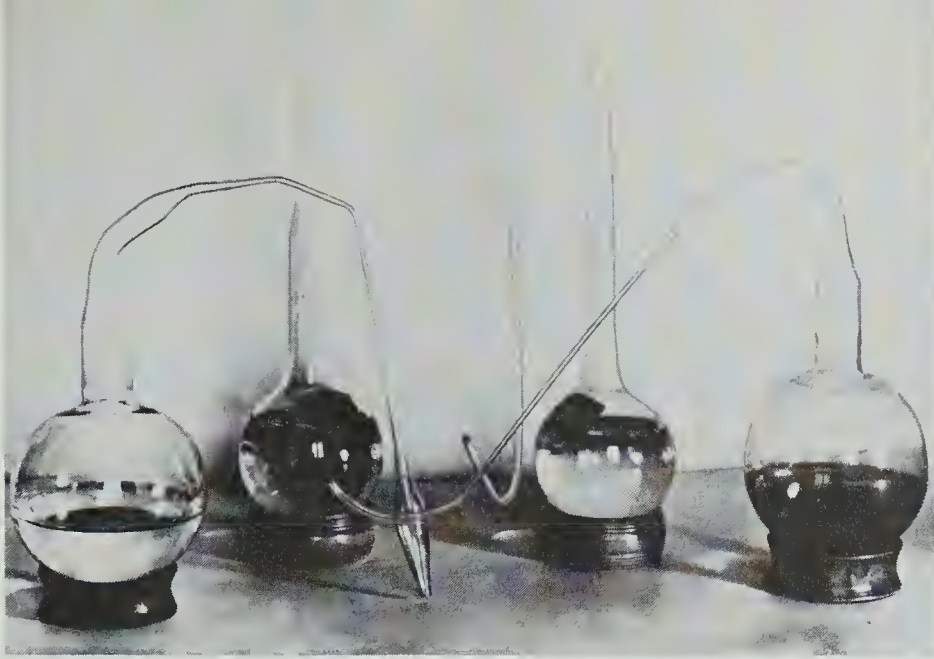
2–3 Cell products If all the cells were removed from an elephant's body, would there be anything left? What if all the cells were removed from a tree? Would anything be left? The answer to both questions is yes. If the cells were removed from an elephant and a tree, you could still recognize both organisms. The reason is that most organisms are made up of other material in addition to cells.

If you looked at an elephant hair under the microscope, you wouldn't see any cells. If you looked at its skin and bones, you would see some cells and a good deal of nonliving material. The same can be said of a tree. You might see some cells in the woody part of a tree. But mostly you would see nonliving material.

The cell theory says that organisms are made up of cells. But that statement is not complete. Most organisms also are made up of products that are manufactured by cells. Elephant hair, and all other hair, is a product made by cells in the skin. Nonliving bone material is produced by cells in the bone. The wood in a tree is a product made by cells that once were alive. Thus there is a better, more complete statement of the cell theory: *All organisms, with a few exceptions, are made up of cells. Most organisms are made up of cells and cell products.*

2–4 Spontaneous generation Where do cells come from? Where does life come from? For many years there was a theory about life that was accepted by some scientists. This theory said that life could just appear out of nonliving material. For example, dirty clothes could produce rats and rotten meat could produce worms. Mud puddles could produce mosquitoes. This theory was called **spontaneous generation**.

Scientists gradually began to destroy the theory of spontaneous generation. By the time of the cell theory, experiments had proven that dirty clothes, rotten meat, and mud puddles do not produce life. Then Louis Pasteur, a French



Shown are the original flasks with which Pasteur disproved the concept of spontaneous generation.

scientist, performed an experiment that did two things. It helped put an end to spontaneous generation as a scientific theory. It also helped establish a theory that has since become an important biological fact: *Organisms can only come from other organisms. Life can only come from life.*

2-5 Virchow's principle The cell theory says that organisms are made up of cells and cell products. A German scientist, Rudolf Virchow, extended the cell theory. He explained where new cells come from. He said that they come from other cells. His statement, "every cell from a cell," became known as **Virchow's principle**.

Virchow's principle opened up a whole new way of thinking about cells. If every cell has come from another cell, then every cell now alive has always been alive. Therefore every living cell has been immortal. It has lived forever, at least since there was a first cell. Life in cells, then, is like a flaming torch that has been kept burning for millions of years.

CHECK YOUR FACTS

1. What did Robert Hooke see and describe in cork?
2. What is a unicellular organism?
3. Is the cell theory still a theory? Why?
4. What are cell products?
5. What are organisms made up of?
6. What is spontaneous generation?
7. What do cells come from?

SCIENCE TERMS

unicellular organisms
cell theory
spontaneous generation
Virchow's principle

duplicate Pasteur's results. The problem was that their solutions contained endospores, which are common in the soil. Endospores cannot be killed by ordinary boiling but must be boiled under pressure, which creates a higher temperature.

In this discussion, *spontaneous generation* is applied to the *de novo* generation of existing forms of life. The spontaneous generation of the first forms of life on earth is an entirely different matter and is not pertinent to this discussion.

MAIN IDEA

Virchow's principle states that every cell has to come from another cell, which means that every cell now alive can trace its origin to the first cell from which it originated.

ANSWERS TO CHECK YOUR FACTS

1. The holes where cells had been.
2. An organism whose body is one cell.
3. No, it is now a proven fact that all organisms, with certain exceptions, are made up of cells.
4. Things that are produced by cells.
5. Cells and cell products.
6. The idea that life can be developed out of nonliving material.
7. Other cells.

MAIN IDEA

The nucleus is the largest cell organelle. It is made up mostly of chromatin that forms into chromosomes during cell division. The nucleus also contains at least one nucleolus.

SCIENCE BACKGROUND

The relative visibility of cell nuclei applies to the light microscope, which is available to most students. The phase-contrast microscope is used in professional and university laboratories for nuclear observation in unstained living cells. The nucleolus is highly variable in cells. It sometimes disappears, then appears again in a different form. There may be more than one nucleolus, however, the number is consistent for any given species.

MAIN IDEA

The cytoplasm, which is the region outside the nucleus, has organelles, such as plastids, and other objects that can be observed through the light microscope.

SCIENCE BACKGROUND

The old term *protoplasm*, which referred to the living material of all cells, is not introduced. The teacher might wish to explain that that term was commonly used when we knew relatively little about the cell and thought of its contents as a kind of magical or ultimate elixir.

General Cell Structure

2–6 The nucleus By the early 1950s cell biologists had acquired knowledge of cells by studying them with the light microscope. They had discovered that the cell contains specialized structures called **organelles**.

The largest cell organelle that is found in most cells is the **nucleus** (nü'klē əs). In some cells, such as those that line the inside of your cheek, the nucleus is easy to see. But for many other cells the nucleus needs to be stained with colored dyes before it becomes visible.

Most of the nucleus is made up of **chromatin** (krō'mə tin), which is a compact mass of very small fibers. The nucleus also contains at least one **nucleolus** (nü klē'ə ləs). This is a small, circular body within the nucleus that is darker than the chromatin.

Cells reproduce by a process called **cell division**. In the first stage of cell division the chromatin changes structure and forms small bodies called **chromosomes** (krō'mə sōmz). The chromosomes contain the hereditary material that determines each cell's characteristics. During cell division equal numbers of chromosomes go to the two cells, called daughter cells, that result from the division.

2–7 The cytoplasm The region outside the nucleus is called the **cytoplasm** (sī'tə plaz əm). Through the light microscope most cytoplasm looks like clear gelatin with various organelles suspended in it. One type of organelle is the **vacuole** (vak'yü ōl), which means "empty space." Actually, vacuoles contain water and other substances.

In plant cells there is often one large vacuole that almost fills the cell. Plant cells also may have vacuoles containing different-colored pigments. Beets and some kinds of cabbage have red pigment in their cell vacuoles. The bright colors of many flowers are also created by pigments in the vacuoles of the flower cells.

Another type of organelle in the cytoplasm of plant cells and some unicellular organisms is called a **plastid** (plas'tid). The most common type of plastid is the **chloroplast** (klôr'ə plast). The chloroplast is green from a pigment it contains called **chlorophyll** (klôr'ə fil). Green leaves get their color from this chlorophyll. The chloroplast and chlorophyll function together to manufacture food.

Other kinds of plastids store food and oils. Some plastids contain red, orange, or yellow pigments. These give tomatoes, oranges, carrots, and many other fruits and vegetables their color.

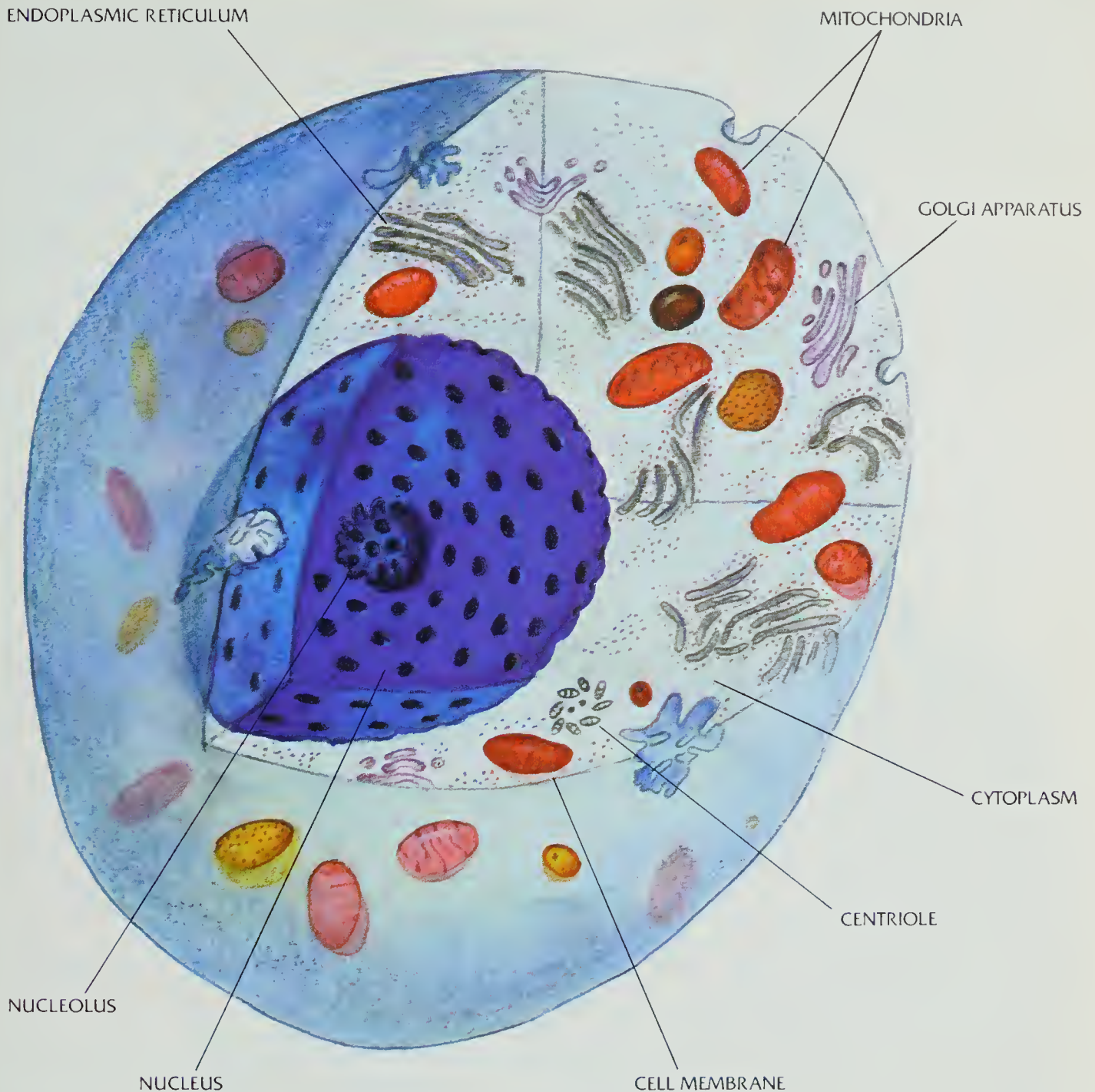


FIGURE 2-1 A diagram of a typical animal cell

2-8 The plasma membrane The cytoplasm is enclosed within a very thin membrane called the **plasma membrane** (plaz'mə mem'brān). It is impossible to see any details in the plasma membrane with the light microscope. Cell biologists learned about the plasma membrane's main characteristic long ago. It is *selectively permeable*, which means that it allows some things to pass through it but not others. The plasma membrane separates

MAIN IDEA

The cytoplasm is enclosed by the very thin plasma membrane that is selectively permeable.

MAIN IDEA

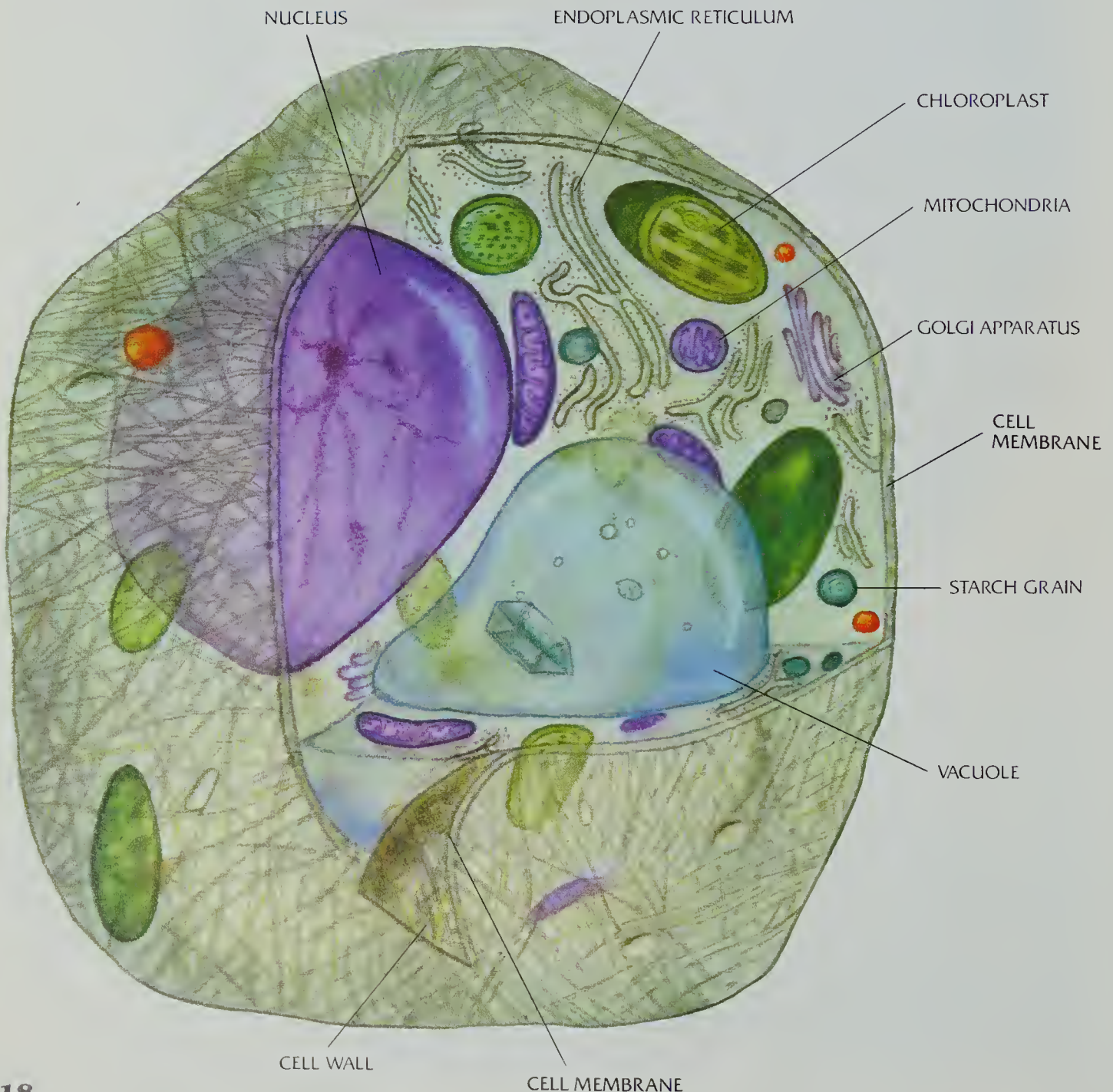
Plants and certain unicellular organisms have a thick cell wall outside the plasma membrane that gives the cell rigidity and keeps it from being destroyed by excess water pressure (turgor).

the cell contents from the outside environment of the cell. By being selectively permeable, the cell membrane controls much of what enters and leaves the cell.

2-9 The cell wall Plant cells and certain unicellular organisms have a thick wall outside the plasma membrane. This wall is called a **cell wall**. The cell wall is a nonliving part of the cell. It is a cell product that is produced inside the cell. It is then transported, bit by bit, to the outside where it forms a protective covering for the cell.

FIGURE 2-2

A diagram of a typical plant cell



The cell wall gives strength to certain cells. This is useful in tall plants like trees. The cell wall also functions like the leather that surrounds the bladder of a football or basketball. Some cells tend to take in more water than they need. The cell wall keeps the pressure of excess water from destroying the cell. Without the cell wall, the cells would swell up, change shape, and burst from internal pressure.

2–10 Exceptions to the cell theory At the beginning of the chapter we said that there were some exceptions to the cell theory. Black bread mold is one exception. It is made up of long tubes of cytoplasm with several nuclei. The tubes are enclosed within a plasma membrane and cell wall, but there are no distinct cells.

Another possible exception is found in certain unicellular organisms having very complex bodies. They have two kinds of nuclei, a mouth, and several other specialized structures. Can organisms with such a complex body still be considered to be unicellular? This question is debatable among biologists.

CHECK YOUR FACTS

1. What is an organelle?
2. What is a nucleolus?
3. What are chromosomes?
4. What is the cytoplasm?
5. What is a vacuole?
6. What is the difference between a plastid and a chloroplast?
7. What is meant by the plasma membrane being selectively permeable?
8. Name two functions of the cell wall.
9. Why is black bread mold an exception to the cell theory?

A Modern View of Cells

2–11 Cells and the electron microscope The electron microscope was invented in the 1930s but did not become widely used until the mid-1950s. At first, cell biologists saw cells magnified 10 000 to 15 000 times. Newer electron microscopes followed along, with better techniques for using them. Cells were seen magnified 50 000 times, then 90 000 times, then over 200 000 times! The cytoplasm no longer looks like clear gelatin with “things” suspended in it. The cytoplasm has a complex structure never dreamed of when it was being studied with the light microscope.

SCIENCE TERMS

organelles
nucleus
chromatin
nucleolus
cell division
chromosomes
cytoplasm
vacuole
plastid
chloroplast
chlorophyll
plasma membrane
cell wall

ANSWERS TO CHECK YOUR FACTS

1. Any specialized structure in the cell.
2. A small, circular body in the nucleus.
3. Bodies made of chromatin that carry the cell's hereditary material and are visible during cell division.
4. The region of the cell outside the nucleus.
5. A body within the cell, filled with water and other substances.
6. A chloroplast is one special kind of plastid.
7. It lets some things pass through but not others.
8. It gives strength and rigidity to certain cells. It also keeps cells from exploding from too much internal water pressure.
9. Much of its body is made up of long tubes with several nuclei but no separate cells.

MAIN IDEA

The electron microscope became widely used in the 1950s for studying cell structure, and a complex new structure was discovered.



The endoplasmic reticulum is a network of membranes that transports materials within cells.

MAIN IDEA

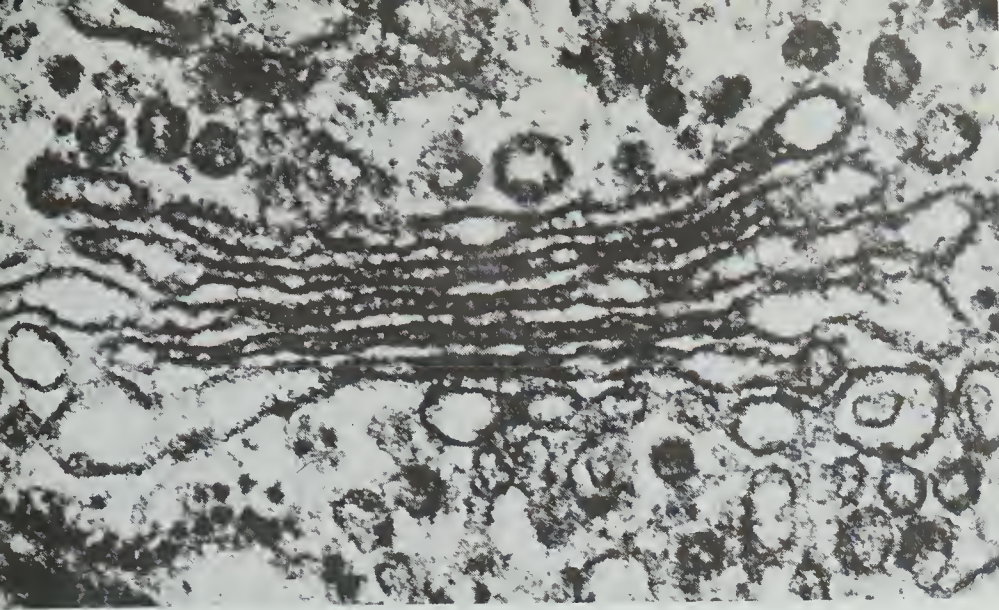
The endoplasmic reticulum (ER) is a network of canals that is usually covered with ribosomes, which help manufacture proteins. The Golgi apparatus, the export machinery of the cell, is thought to be a specialized part of the ER.

2–12 The endoplasmic reticulum The discovery that the cytoplasm is full of membranes was one of the major surprises seen with the electron microscope. These membranes are interconnected and form a system called the **endoplasmic reticulum** (en dō plaz'mik ri tik'yə ləm), abbreviated *ER*.

The membranes of the ER have two layers. The space between the layers is like a system of canals. Materials are moved throughout the cell inside the ER. It was also discovered that the ER is continuous, with a double-layered membrane surrounding the nucleus. It is believed that materials can move back and forth, from the nucleus to the outside of the cell, through the ER.

In most cells the outside layers of the ER are covered with small, round organelles called **ribosomes** (rī'bə sōmz). The ribosomes help manufacture proteins that are very important in the cell. Cells that manufacture many proteins have so many ribosomes that the ER has a rough appearance and is called rough ER. Other cells that manufacture few or no proteins do not have ribosomes lining the outside of the ER. The ER of such cells is called smooth ER.

Also in the cytoplasm is a group of membranes that look like a stack of flattened balloons. These membranes make up the **Golgi apparatus** (gol'jē ap ə rā'təs), which is thought to be a specialized part of the ER.



The Golgi apparatus packages and transports materials to be secreted to the exterior of the cell.

SCIENCE BACKGROUND

The Golgi apparatus was discovered around 1900 by Camillo Golgi, when he stained barn owl nerve cells with a dye containing silver. However, for the next 50 years, until confirmation with the electron microscope, many biologists refused to believe that it existed. They are still debating whether the Golgi apparatus is a permanent or transient part of the ER.

Cells that do not have a Golgi apparatus are mature sperm cells and red blood cells.

The Golgi apparatus is the main part of a cell's "exporting machinery." Products for export move through the ER into the "flattened balloons," which serve as containers. Inside the containers the cell products are changed in various ways and made ready for export. Then the containers break off and form vacuoles that move through the cytoplasm. The vacuoles move to the plasma membrane and are released by the process of **exocytosis** (ek sō sī tō'sis).

2-13 Mitochondria Scattered throughout the cytoplasm are tiny organelles called **mitochondria** (mī to kon'drē ə). They were first seen through the light microscope as tiny particles "bouncing" around in the cytoplasm. Now, with the electron microscope, we see that they are shaped like sausages and jelly beans.

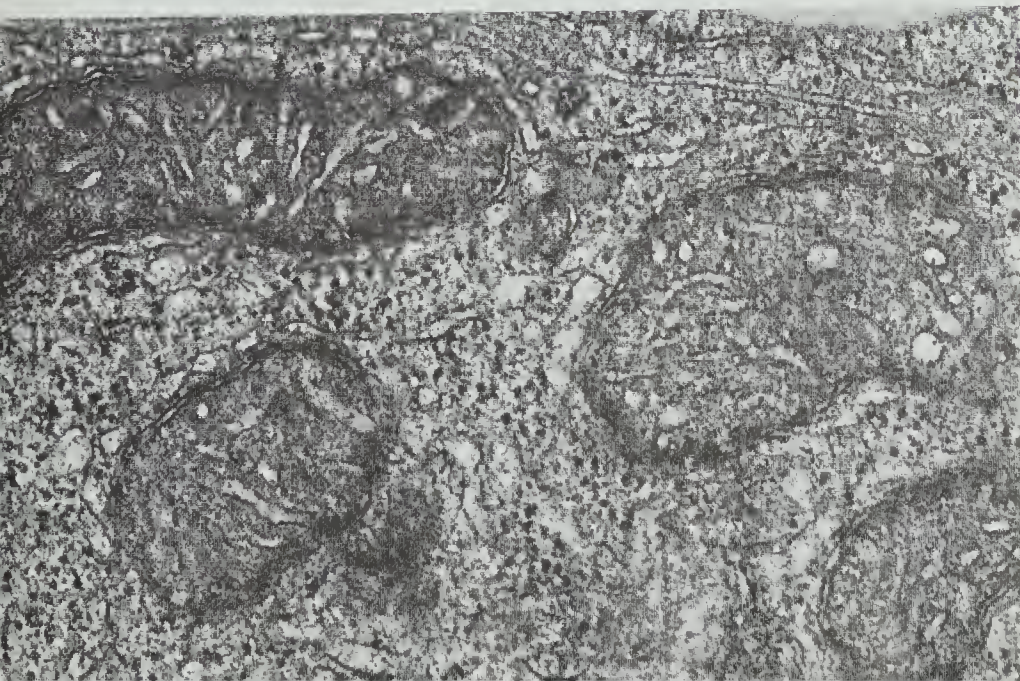
A cross-sectional view of a mitochondrion shows that it has two membranes. The inner membrane has folds called **cristae** (kris'tē) that form partial cross-walls inside the mitochondrion.

MAIN IDEA

The mitochondria are oval or elongated bodies with inner cross-walls that change digested food into energy that can be used by the cell.

SCIENCE BACKGROUND

Not discussed in this section are the tiny electron transport particles that cover the surface of the cristae and look like a forest of mushrooms. These will be discussed in relation to energy transformation in Chapter 5.



A mitochondrion is enclosed in two membranes. Mitochondria are the centers of cellular respiration.

The mitochondrion is called the “powerhouse” of the cell because it changes digested food into energy. This energy does most of the work in cells, and for the whole organism. Cells that perform great amounts of work, such as the flight-muscle cells of hummingbirds, are packed full of mitochondria. Cells that do little work have a much smaller number of mitochondria.

MAIN IDEA

Chloroplasts, when observed with the electron microscope, are seen to have stacks of grana that provide a large surface area for the absorption of light, which is used to manufacture food.

SCIENCE BACKGROUND

In a typical mesophyll leaf cell there may be 50 chloroplasts. Investigators now think chloroplasts have the ability to orient themselves in the cytoplasm, so that the flat membranes are exposed directly to sunlight. A more detailed discussion of chloroplast structure and function is in Chapter 5.

2–14 Chloroplasts Chloroplasts were easily seen through the light microscope. However, the electron microscope shows that they have a very complex inner structure.

Throughout the chloroplast there are groups of membranes that look like stacks of pancakes. These stacks are called **grana** (grā'nə). The grana provide a large surface area for sunlight to strike and be absorbed. The green chlorophyll that is in the grana helps change sunlight into chemical energy. This chemical energy is then used to manufacture food.

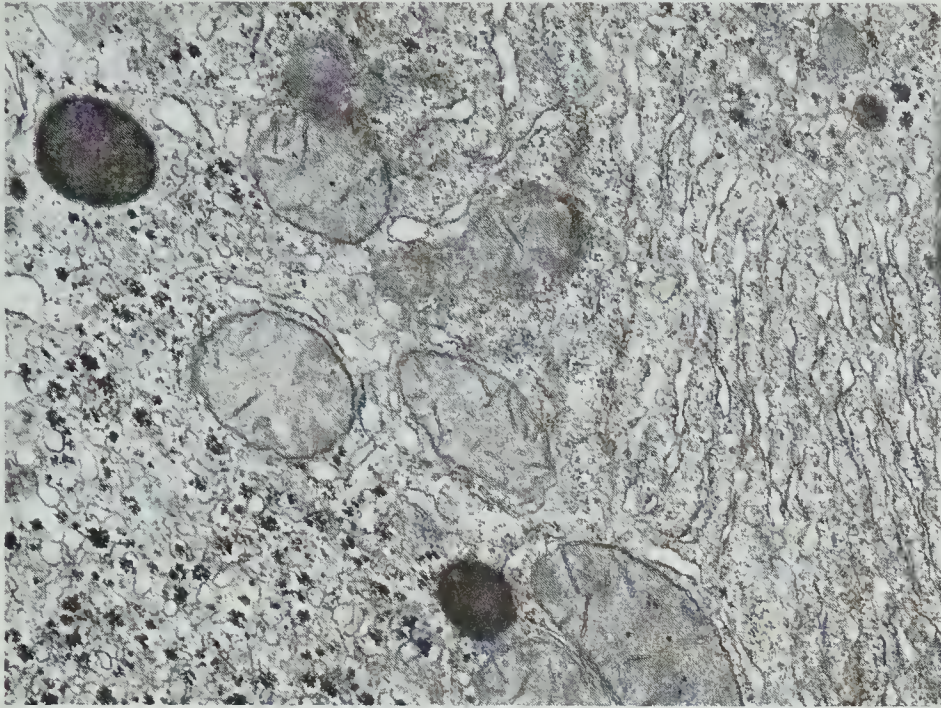


Chloroplasts have a double-membrane system. The stacked membranous discs, or grana, are interconnected by tubules.

MAIN IDEA

Lysosomes are organelles that contain digestive enzymes for breaking down various things in the cell.

2–15 Lysosomes Scattered throughout the cytoplasm are small organelles called **lysosomes** (lī'sə sōmz). The lysosomes contain chemicals that digest, or break down, small particles of food that enter the cell. The lysosomes also digest worn out parts of the cell, so the raw materials can be used again. Thus lysosomes are both the cell's digestive system and its recycling center.



Lysosomes act as the disposal units of the cytoplasm. They are essential to the internal maintenance of the cell.

The chemicals in the lysosomes also can digest the cell itself if the membranes of the lysosome are broken. For this reason the lysosome is also called a “suicide bag.”

2–16 Microtubules A big surprise revealed by the electron microscope was that most cells have a **cytoskeleton** (sī tə skel’ə tən). This is a structure that gives strength to the cell body and helps maintain its shape.

The units of the cytoskeleton are called **microtubules** (mī krō tū’byūlz). They are long, thin, hollow tubes. They function like braces and beams that give strength and shape to a building.

Microtubules also function in cell movement. They help move the chromosomes during cell division. They also form parallel bundles in hairlike extensions of the cell. These hairlike extensions are common in unicellular organisms. They are called **cilia** (sil’ē ə) or **flagella** (flə jel’lə) and they whip back and forth, propelling the organism.

2–17 Centrioles Most animal cells and some plant cells have two rod-shaped structures called **centrioles** (sen’tre ōlz). They are made of microtubules arranged like a stack of soda straws. The centrioles are arranged so that one of them is always perpendicular to the other.

SCIENCE BACKGROUND

Self-destruction of cells, called *autolysis*, is a normal function in some tissues—for example, in the tadpole’s tail during its metamorphosis into a frog. The lysosome was first observed in an ultracentrifuged fraction of the cell, before it was observed and identified with the electron microscope.

MAIN IDEA

Cells have a cytoskeleton made up of microtubules, which strengthen the cell, assist in moving chromosomes during cell division, and form hairlike extensions used in locomotion.

SCIENCE BACKGROUND

One of the most striking examples of the uniformity of life is the fact that all cilia and flagella are made up of microtubules arranged so that a cluster of nine microtubules are around the circumference and usually two microtubules are in the center. This is often called a *nonad*, or $9 + 2$ pattern.

MAIN IDEA

Most animal cells and some plant cells have two centrioles that function during cell division.

The centriole is made up of nine parallel triplets of microtubules.

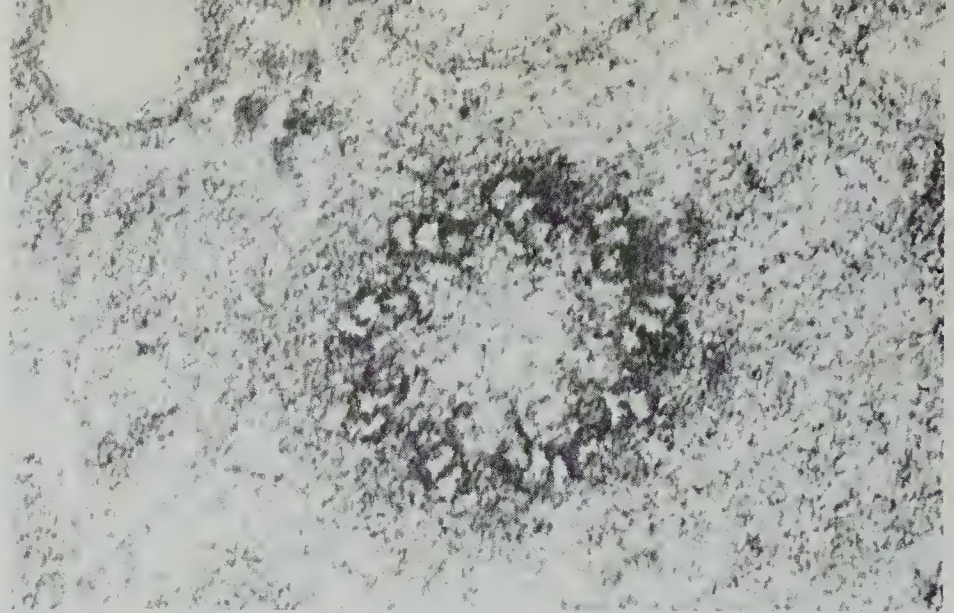
SCIENCE BACKGROUND

Centrioles also have a nonad structure and always appear in the cells of organisms that develop cilia or flagella during some stage of their life cycle. In cells with cilia and flagella, similar or identical structures form the basal bodies, or *kinetosomes*, from which the cilia or flagella originate.

MAIN IDEA

The plasma membrane is made up of protein and fat layers and may have fingerlike projections, called microvilli, that increase the absorptive area of cells. Also the plasma membrane may form vacuoles that take in liquids and solids.

The plasma membrane is a triple-layered structure: two electron-dense lines separated by a lightly stained space.



The centrioles lie close to the nucleus. They probably function only during cell division. During cell division they make up part of the machinery that divides the chromosomes between the two daughter cells.

2-18 The structure of the plasma membrane With the electron microscope the plasma membrane appears as a three-layered membrane. The outer and inner layers are darker and are composed of protein material. In between the protein layers, like meat in a sandwich, is a layer of fatty material. Actually there are two layers of the fatty material, but they appear as one.

Another discovery was that the plasma membrane is not smooth, as it appears to be under the light microscope. Some plasma membranes have many small, fingerlike projections called **microvilli** (mī krō vil'ī). Microvilli are common in cells that are actively absorbing materials. The microvilli greatly increase the surface area through which materials are absorbed.





Microvilli increase the cell membrane surface area and the absorptive capability of cells.

Other extensions of the plasma membrane form tiny vacuoles. These vacuoles form around droplets of liquid or small solid particles. As the vacuole closes it may break off the plasma membrane and move into the interior of the cell. This process is the reverse of exocytosis, which is an exporting process. But two different terms are used to describe the processes of taking materials into the cell. When liquids are taken into the cell, the process is called **pinocytosis** (pi nō si tō'sis), which means "cell drinking." When solid material is taken into the cell, the process is called **phagocytosis** (fag ə sī tō'sis), which means "cell eating." Usually much larger vacuoles are formed during phagocytosis.

2-19 Another type of cell There are two general types of cells found in nature. Most of them are of the type that we have been describing. These are called **eucaryotic** (yū'kar ē o tik) **cells**. This name means "cells with a true nucleus."

The second type of cell has a much simpler structure. It is called a **procaryotic** (pro'kar ē o tik) **cell**. This name means "before the nucleus." Procaryotic cells have no separate nucleus and cytoplasm. The nuclear material that controls the heredity of eucaryotic cells is scattered throughout the interior of procaryotic cells.

Procaryotic cells have no membrane-enclosed organelles. For example, they have no mitochondria, chloroplasts, Golgi bodies, centrioles, or endoplasmic reticulum. The procaryotic cell does have ribosomes, which help make proteins, but they are scattered throughout the cell.

SCIENCE BACKGROUND

More and more in biological literature the term *endocytosis* is used instead of the more specific terms *pinocytosis* and *phagocytosis*.

SCIENCE BACKGROUND

A procaryote is an organism with procaryotic cells; a eucaryote is an organism with eucaryotic cells. Also, in everyday use, some biologists use the abbreviated terms *procell* and *eucll* for the procaryotic and eucaryotic cells. It is not clear at this time whether these terms will become widely accepted.

MAIN IDEA

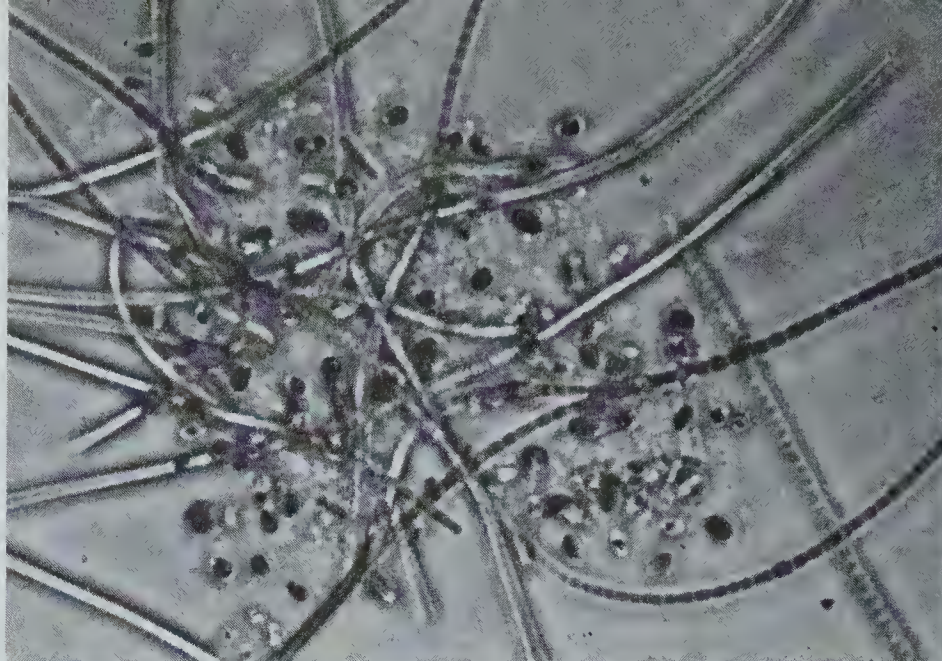
Eucaryotic cells have a nucleus and the organelles that have been described. A more primitive cell is the procaryotic cell that lacks a distinct nucleus and most organelles. The bacteria and blue-green algae have procaryotic cells and are placed into a separate group of organisms called monerans.

SCIENCE TERMS

endoplasmic reticulum
ribosomes
Golgi apparatus
exocytosis
mitochondria
cristae
grana
lysosomes
cytoskeleton
microtubules
cilia
flagella
centrioles
microvilli
pinocytosis
phagocytosis
eucaryotic cells
procaryotic cell

ANSWERS TO CHECK YOUR FACTS

1. In the mid-1950s.
2. It is a network of membranes in the cytoplasm that functions to transport materials.
3. Rough ER is covered with ribosomes; smooth ER is not.
4. It is a stack of membrane-covered sacs that prepares and helps export products from the cell.
5. The process by which materials are passed out of the cell.
6. It is a sausage-shaped double-membrane organelle with cross-walls, called cristae. It converts digested food into energy and is called the "powerhouse" of the cell.
7. Stacks of membranes in chloroplasts, where food is manufactured.
8. Digests food that enters the cell; and breaks down cell materials, so the raw materials can be recycled.
9. An internal skeleton, made of microtubules, which helps the cell maintain its shape and



Bacteria and blue-green algae consist of procaryotic cells. Procaryotic cells lack a nucleus.

Only two groups of organisms have procaryotic cells. One group includes all the bacteria, which are unicellular organisms. The other group includes all the blue-green algae. The blue-green algae have chlorophyll, which they use to manufacture food. Together, the bacteria and blue-green algae are placed in the kingdom Monera and are called monerans.

CHECK YOUR FACTS

1. When did the electron microscope become widely used to study cells?
2. What is the structure and function of the ER?
3. What is the difference between rough ER and smooth ER?
4. What is the structure and function of the Golgi apparatus?
5. What is exocytosis?
6. What is the structure and function of a mitochondrion?
7. What are grana?
8. Name two functions of the lysosome.
9. Describe the cytoskeleton.
10. When do centrioles function?
11. Describe the structure of the plasma membrane.
12. What kinds of cells would have many microvilli?
13. What is the difference between exocytosis, pinocytosis, and phagocytosis?
14. How do procaryotic cells differ from eucaryotic cells?
15. What are monerans?

SUMMARY

In the 1600s the English scientist Robert Hooke first described the unit of living organisms, which he called the cell. Later work led to the cell theory, which states that all organisms, with some exceptions, are composed of cells and cell products. Another idea—that life could spring from nonlife—was finally proved false by the French scientist Louis Pasteur. The question of where cells originate was finally settled by the acceptance of Virchow's principle. This states that every cell comes from another cell.

There are many specialized structures in the cell and these are called organelles. The largest organelle is the nucleus. The region outside the nucleus is called the cytoplasm.

REVIEW QUESTIONS

1. What parts of a cell can be seen with the light microscope?
2. What cell organelles are called the “powerhouses”?
3. Name two structures produced by plant cells but not by animal cells.
4. What structure is much more common in animal cells than in plant cells?
5. A cell that manufactures lots of proteins is sure to have many of what organelle?
6. What structures are likely to be found along the plasma membrane of cells that absorb food from the small intestine?
7. What is the difference between a moneran and all other organisms?
8. Microtubules are the structural units that make up what organelles?
9. What organelles would be plentiful in cells that are actively engaged in phagocytosis?
10. What is one likely characteristic of cells that do not have a Golgi apparatus?

ANALYSIS AND APPLICATION

1. A researcher spun cell fragments in a centrifuge, which caused them to separate into layers. It was discovered that one of the layers consisted of bodies with digestive enzymes. This was how one organelle was discovered before it was actually seen in the electron microscope. What organelle would that have been?
2. Many cells in plants do not have chloroplasts. Where would those cells most likely be located?

gives it strength.

10. During cell division.
11. Two layers of fatty material surrounded by an outer and an inner layer of protein.
12. Cells that absorb materials from their surroundings.
13. Exocytosis is a process of removing things from cells. Pinocytosis and phagocytosis do the opposite; they take things into cells. Pinocytosis takes in liquids, and phagocytosis takes in solid material.
14. Prokaryotic cells do not have a nucleus or membrane-enclosed organelles.
15. Organisms whose bodies are made up of prokaryotic cells; bacteria and blue-green algae.

ANSWERS TO REVIEW QUESTIONS

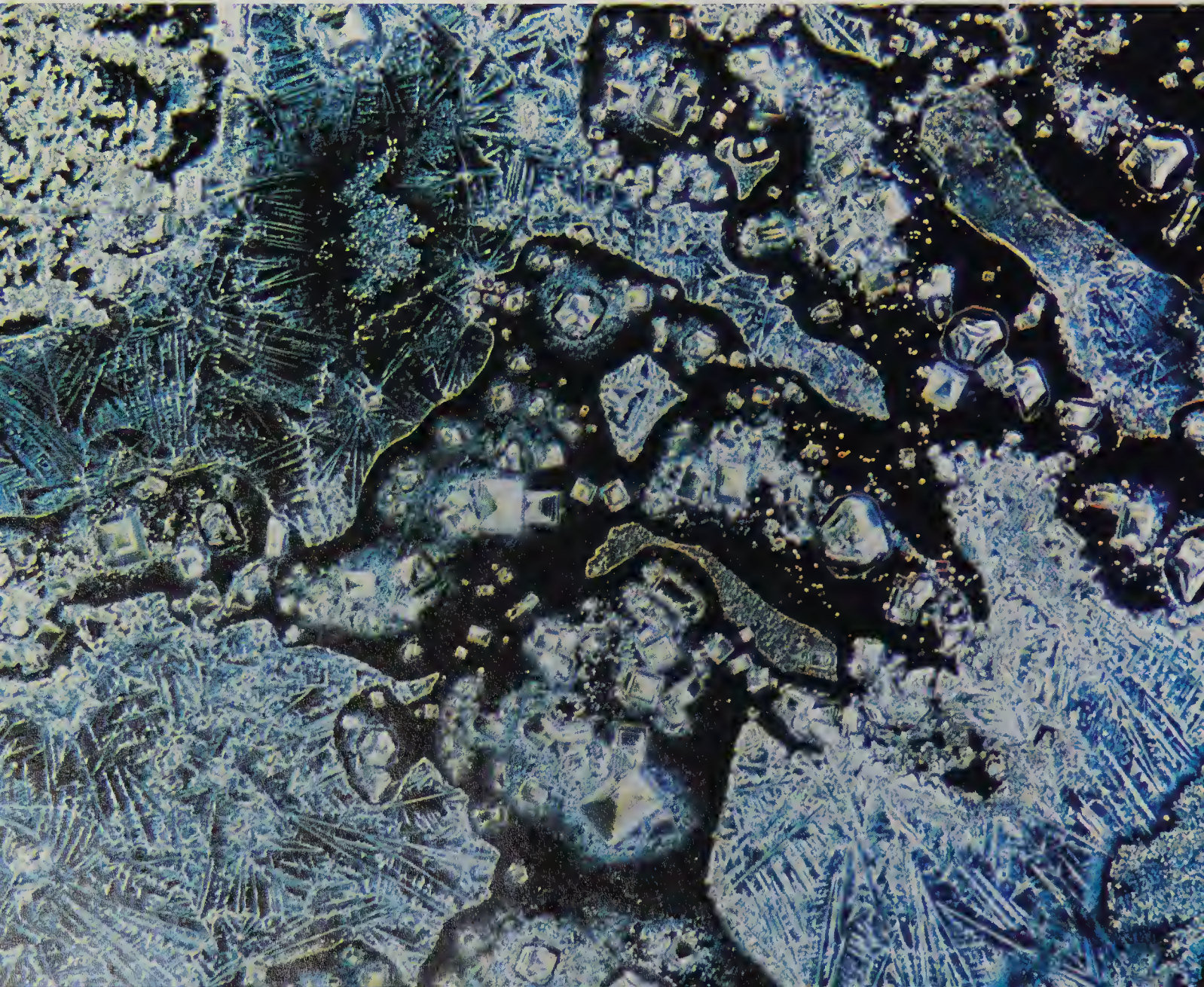
1. Cell wall, nucleus, nucleolus, chromatin, chromosomes, vacuoles, plastids, and mitochondria.
2. Mitochondria.
3. Cell wall and chloroplasts.
4. The centriole.
5. The ribosome.
6. Microvilli.
7. Monerans are made up of prokaryotic cells; all other organisms are made up of eukaryotic cells.
8. Cilia, flagella, and centrioles.
9. Lysosomes, because the solid material has to be broken down.
10. They do not produce products that need to be exported from the cell.

ANSWERS TO ANALYSIS AND APPLICATION

1. The lysosome.
2. In parts of the plant that receive no light.

Investigation 7 from *Laboratory Investigations in Biology* can be done with this chapter.

3 Molecules



OBJECTIVES

- To explain basic atomic and molecular structure
- To understand the basic nature of the covalent and ionic bonds
- To understand water's unique properties of polarity
- To know the basic structure of carbohydrates
- To understand the basic structure of the typical fat molecule
- To know that proteins are made up of 20 different amino acids arranged in chains

What Are Molecules?

3-1 Molecules make up living matter Can you imagine what a cell organelle would look like if it were magnified 5 million times? Suppose, for example, that an organelle like the chloroplast could be made as large as a football and you could hold it in your hand. What would you see when you observed this organelle? You would see **molecules**. Molecules are the subunits that make up organelles. Molecules are the building blocks that make up *all living matter*.

3-2 Molecules are made up of subunits Now imagine a molecule from an organelle enlarged several million times. What would you see now? You would see **atoms**, which are the subunits that make up all molecules. Atoms are the basic building blocks of *all matter*.

3-3 The simplest atom Only 92 different kinds of atoms have been found throughout the universe. (Another 11 have been created in minute quantities in the laboratory.) The simplest atom is the hydrogen atom. The central part of the hydrogen atom, called the **nucleus**, has just one particle. This particle is called a **proton** (prō'ton). The proton is a particle with a positive electrical charge.

Another particle, called an **electron** (i lek'tron), is in orbit around the hydrogen nucleus. The electron has a negative electrical charge. With 1 electron and 1 proton, the electrical charges are balanced. Thus the hydrogen atom itself has no electrical charge. It is said to be *neutral*.

MAIN IDEA

Molecules are the subunits that make up all organelles.

SCIENCE BACKGROUND

It is recommended that ball-and-stick models be used whenever any molecule is discussed.

MAIN IDEA

Molecules are made up of atoms, which are the building blocks of matter throughout the universe.

MAIN IDEA

There are 92 different atoms found in nature. The simplest atom, hydrogen, has one positively charged particle called a proton in its nucleus and one negatively charged particle called an electron that orbits around the nucleus.

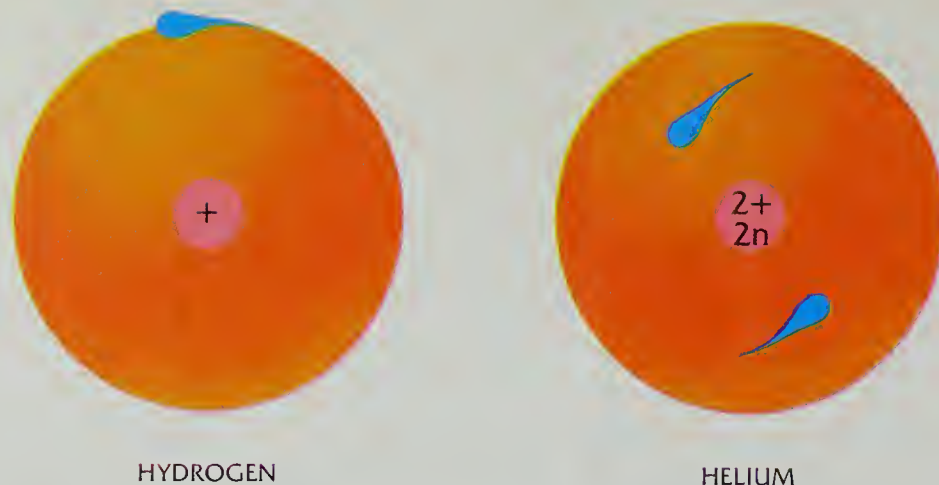


FIGURE 3-1 Diagrams of the hydrogen atom and the helium atom

MAIN IDEA

Each of the 92 different atoms has a different number of protons in its nucleus. This number is called the atomic number. A substance made up of atoms with the same atomic number is called an element.

MAIN IDEA

Four of the 92 elements—carbon, hydrogen, oxygen, and nitrogen—make up 97 percent of all living matter. In addition to protons and electrons, atoms have uncharged particles called neutrons. The mass number is the number of protons plus neutrons in the nucleus.

3-4 Atomic number and elements Each of the 92 different kinds of atoms has been given a number based on the number of protons in its nucleus. This number is different for each kind of atom and it is called the **atomic** (ə tom'ik) **number**. Hydrogen has 1 proton in its nucleus. Therefore its atomic number is 1.

A substance made up entirely of atoms with the same atomic number is an **element** (el'ə mənt). Hydrogen gas is an example of an element.

3-5 More particles We have said that there are 92 basic kinds of atoms in the universe and that each kind has a different atomic number. They are the building blocks that make up 92 different elements. However, only four elements make up about 97 percent of all living matter. Hydrogen is one of the elements. The other three are carbon, nitrogen, and oxygen.

The carbon atom has an atomic number of 6. It has 6 protons in its nucleus and 6 electrons in orbit. However, the carbon atom has an additional kind of particle. In the carbon nucleus there are also six particles called **neutrons** (nü'trons). Neutrons are particles which have no electrical charge.

The nitrogen atom has the atomic number of 7. It has 7 protons, 7 electrons, and 7 neutrons. Oxygen has the atomic number of 8 and has 8 protons, 8 electrons, and 8 neutrons. What particles would you expect in an atom with an atomic number of 15?

Phosphorous is the next most abundant element in living matter. The phosphorous atom has an atomic number of 15. It has 15 protons and 15 electrons. But it has 16 neutrons in its nucleus.

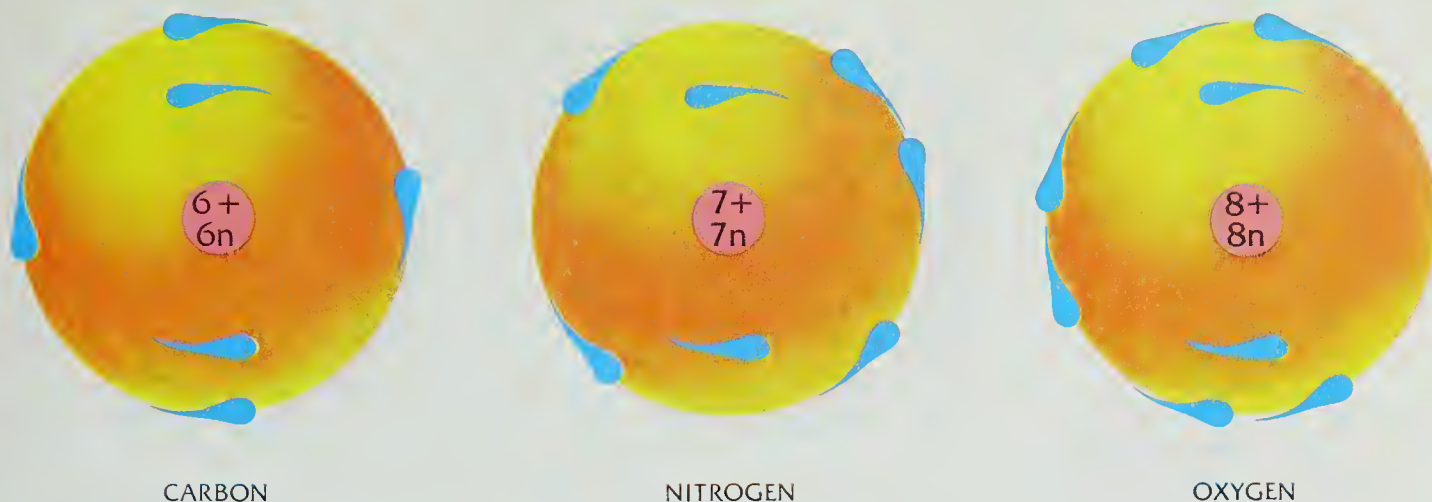


FIGURE 3-2 The carbon, nitrogen, and oxygen atoms

From the atomic number we can determine the number of protons and electrons in an atom but not the number of neutrons. In other words, the number of neutrons does not always equal the number of protons. To determine the number of neutrons in an atom we also must know its **mass number**. The mass number is the total number of protons and neutrons in the nucleus. The mass number of phosphorous is 31. By subtracting the atomic number (number of protons) from the mass number, we can determine that the element phosphorous has 16 neutrons ($31 - 15 = 16$).

3-6 Isotopes Earlier we described the hydrogen atom and said that it has 1 proton and 1 electron. Actually this describes 99.98 percent of the hydrogen atoms found in nature. The remaining 0.02 percent (2 out of every 10 000) also has 1 neutron in the nucleus. Thus the mass number of ordinary hydrogen—the most common form—is 1. The mass number for the other, less common form, called deuterium, is 2. Such atoms, having the same atomic number but different mass numbers, are called **isotopes** (ī'sə tōpz). The symbol for the isotope of ordinary hydrogen is 1_{H} . The symbol for deuterium is 2_{H} .

3-7 Neutral atoms and ions An atom having the same number of protons and electrons has no electrical charge and is called a neutral atom. However, there are many atoms, or groups of atoms, that are not neutral. They are called **ions** (ī'ənz).

An example is the sodium ion that is found in your blood. The sodium ion has the atomic number of 11. It has 11 protons in its nucleus. However, the sodium ion has

SCIENCE BACKGROUND

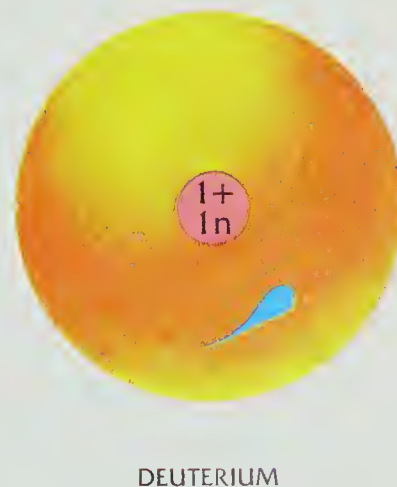
A third isotope of hydrogen is tritium, 3_{H} .

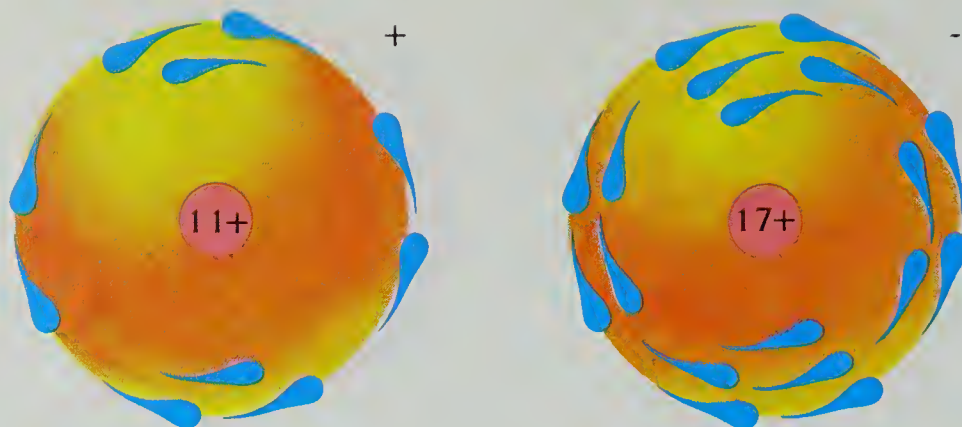
MAIN IDEA

Isotopes are atoms that have the same atomic number but different mass numbers because of varying numbers of neutrons.

FIGURE 3-3

Deuterium has one proton and one neutron in its nucleus.





SODIUM ION

CHLORIDE ION

FIGURE 3-4 Diagrams of sodium and chlorine ions

MAIN IDEA

Atoms with the same number of protons and electrons are neutral atoms. Atoms with a number of electrons more or less than the number of protons have a positive or negative charge and are called ions.

MAIN IDEA

The attractive force that holds two or more atoms together is a chemical bond. The ionic bond results from the attraction of ions with unlike charges. The covalent bond is a very strong bond that results when two atoms share orbiting electrons. A molecule is made up of two or more atoms linked by chemical bonds. A chemical compound is the bonding of two or more different atoms.

SCIENCE TERMS

molecules
atoms
proton
electron
atomic number
element
neutrons
mass number
isotopes
ions
chemical bond
ionic bond
covalent bond
chemical compound

lost 1 of its electrons. It only has 10 electrons orbiting the nucleus. Therefore the sodium ion has one more positive charge than negative charge, which gives the atom a net positive charge. The symbol for the sodium ion is Na^+ .

Chlorine ions are also in your blood. (Chemists call them chloride ions, but they are really atoms of chlorine.) The atomic number of chlorine is 17. However, the chlorine ion has gained an extra electron. There are 18 electrons orbiting a nucleus with 17 protons. This gives the chlorine ion one more negative charge, which causes the whole ion to have a negative charge. The symbol for the chlorine ion is Cl^- .

3-8 Bonds and molecules Atoms seldom exist alone in nature. Usually atoms are linked to other atoms by an attractive force called a **chemical** (kem'ə kəl) **bond**, often described more simply as a **bond**.

There are three basic types of bonds in living matter, two of which will be discussed here. One type is the **ionic** (ī on'ik) **bond**. This bond is formed by the attraction between ions with unlike charges. An example is the attraction between a sodium ion (Na^+) and a chlorine ion (Cl^-). Under certain conditions sodium and chlorine ions will bond to form a completely new substance called sodium chloride, or table salt.

A second type of bond results when two atoms collide and one or more of their electrons end up orbiting both nuclei. With this kind of bonding there is an actual sharing of electrons between two atoms. This sharing arrangement results in a very strong bond called a **covalent** (kō vā'lənt) **bond**.

When two or more atoms are linked together by a chemical bond, the resulting matter is called a molecule. Some molecules are formed out of two atoms that are exactly alike. Examples are hydrogen and oxygen molecules. Each hydrogen molecule consists of two hydrogen atoms linked together by a covalent bond. Two oxygen atoms make up each molecule of oxygen. The molecular formula for a molecule uses the symbol for the atom and a subscript number telling how many atoms are linked together. For example, the molecular formula for the hydrogen molecule is H_2 and for the oxygen molecule is O_2 .

Other kinds of molecules result from the bonding of two or more different kinds of atoms. Such a molecule is a **chemical compound**, or simply **compound**, which has characteristics that are totally different from those of any of the atoms it contains. An example is the compound called water. Water is made up of two atoms of hydrogen linked by covalent bonds to one atom of oxygen (H_2O). Hydrogen is a very light, invisible, explosive gas. Oxygen also is an invisible gas. Water, of course, is a liquid that is completely unlike either hydrogen or oxygen.

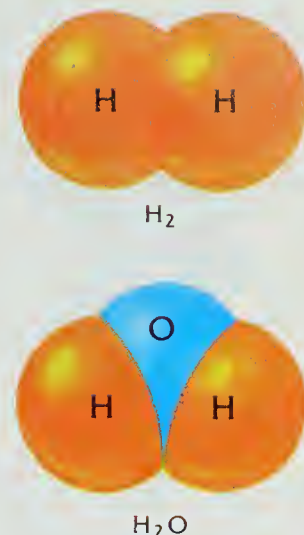


FIGURE 3-5

A hydrogen molecule is made up of two atoms of hydrogen. A water molecule is made up of two atoms of hydrogen and one atom of oxygen.

ANSWERS TO CHECK YOUR FACTS

1. Molecules are made up of atoms.
2. Carbon, oxygen, nitrogen, and hydrogen.
3. The hydrogen and oxygen atoms that make up the water molecule do not have the same atomic number.
4. There are 47 electrons and 60 neutrons.
5. Atoms with the same atomic number but with different mass numbers.
6. An atom or group of atoms that have a positive or negative charge.
7. Sodium ion or chloride ion. Both are in the blood.
8. A covalent bond.
9. CO_2 and CH_3 are compounds. All are molecules.

CHECK YOUR FACTS

1. How are molecules related to atoms?
2. What are the four most common elements that make up living matter?
3. Water (H_2O) is not an element. Why?
4. The element silver has an atomic mass of 107. Its atomic number is 47. How many electrons and neutrons are in an atom of silver?
5. What are isotopes?
6. What is an ion?
7. Give an example of an ion that is found in the human body. Where is it found?
8. Name a strong chemical bond where electrons are shared by atoms.
9. Which of the following are compounds? Which are molecules? (CO_2 , H_2 , O_2 , CH_3)

Water

3-9 The most abundant molecule The most abundant molecule in all organisms is water. About two thirds of the human body is water. The bodies of jellyfish, which live in the ocean, may be as much as 95 percent water.

MAIN IDEA

Water is the most abundant molecule in organisms.

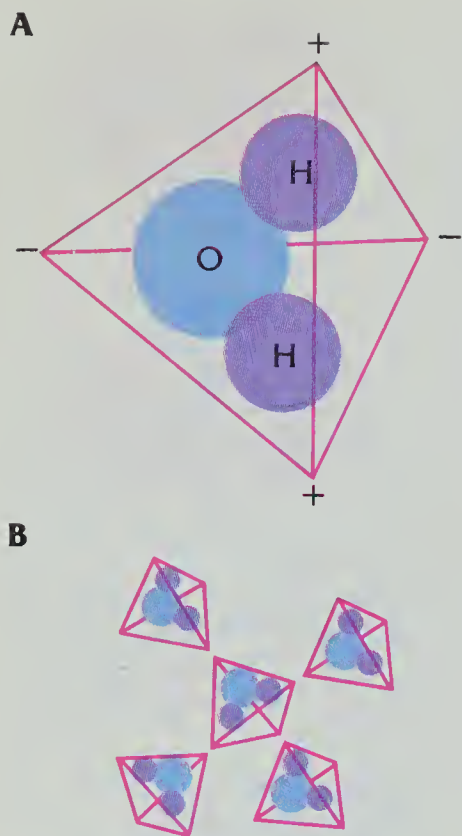


FIGURE 3-6

The water molecule showing the four-cornered distribution of positive and negative charges. Each water molecule can form hydrogen bonds with four other water molecules.

MAIN IDEA

The unlike charges in different regions of the water molecule cause them to form hydrogen bonds with each other, and with charged regions of other molecules.

Why do organisms have so much water in their bodies? An understanding of the structure and behavior of the water molecule will help explain its importance in organisms.

3-10 Water is a polar molecule Note the diagram of the water molecule in Figure 3-6. All water molecules have this same triangular shape. Note in the diagram the relative size of the oxygen nucleus (with 8 protons) as compared with the hydrogen nuclei of 1 proton each.

The bonds that hold the water molecule together are covalent bonds. This means that the two hydrogen's electrons spend part of their time orbiting the oxygen nucleus. Also, two of oxygen's electrons are orbiting the hydrogen nuclei. But because of the greater size and pulling power of the bigger oxygen nucleus, the electrons spend more time orbiting the oxygen nucleus. This results in an imbalance in electrical charge over the whole molecule. The oxygen end of the molecule has a slight negative charge because the electrons spend more time there. The hydrogen end of the molecule has 2 protons that are bare some of the time. This causes the hydrogen end of the molecule to have a slight positive charge. The result is that the water molecule has two poles, one negative and the other positive. Therefore, water is called a **polar** (pō'lər) **molecule**.

3-11 Cohesion and hydrogen bonding The polar nature of the water molecule causes each molecule to behave like a little magnet. When two water molecules are close together, they are attracted to each other. And, like two magnets, each with a north and south pole, the water molecules are attracted at the poles with unlike charges. The negative end of one water molecule attracts the positive end of another water molecule. This attraction of like molecules to each other is called **cohesion** (kō hē'zhan).

While many organisms live within the water, the water strider actually lives on the surface. It is supported by surface tension resulting from cohesive forces.



The attraction of water molecules to each other is an example of a third type of chemical bond, called a **hydrogen** (hī'drə jən) **bond**. The hydrogen bond is much weaker than the ionic and covalent bonds. Hydrogen bonds are easily broken and re-formed. In water they are constantly being broken and re-formed. Hydrogen bonds in other molecules, which will be discussed later, are more stable and are of extreme biological importance.

3-12 The universal solvent and dispersal medium Many other molecules have polar regions with unequal charges. Sugar is an example. Sugar and most other polar molecules are much larger than the water molecule. But when a molecule such as sugar is placed in water, hydrogen bonds are immediately formed with water molecules. The water molecules then behave like a giant fleet of tugboats. They attach to the larger molecule, and because they are in constant motion, they spread or disperse the larger sugar molecules evenly throughout the liquid. This process creates a sugar-water **solution** (sə lū'shən), which means that the sugar molecules are dispersed evenly throughout the liquid.

A substance like water that can disperse other substances and create solutions is called a **solvent** (sol'vənt). (The substance being dissolved is called the **solute**.) Because of the polar nature of the water molecules and the abundance of water on earth, water solutions are both common and very important. For this reason, water is often called the universal solvent.

The role of water as a solvent is very important in organisms. However, in organisms, water is more accurately described as a **dispersal** (dis pēr'səl) **medium**, which has a broader meaning. Because of its ability to form hydrogen bonds, water acts like a fleet of tugboats and helps disperse polar molecules in cells and in body fluids, such as blood.

But water also disperses molecules that are not polar and do not form hydrogen bonds with it. To imagine how this is done, think of ten rafts being placed in the middle of a large river. Soon the rafts will be dispersed by the current of the river. In organisms, water disperses both polar and nonpolar molecules in the same way—by the force of moving water in a current. Such currents are found in moving fluids in organisms, such as sap in plants and blood in animals. And a close look at the cell cytoplasm, which is mostly water, reveals currents that on a smaller scale are as powerful as a river. So water functions as the dispersal medium in organisms because of its solvent ability and because of the physical force of its current.

SCIENCE BACKGROUND

The hydrogen bonding in protein molecules and between the nucleotides of DNA are of extreme biological importance.

MAIN IDEA

Because water is a polar molecule, it can form hydrogen bonds with many other materials, dispersing them in solutions. This is important in organisms because it enables water to disperse other important molecules.

SCIENCE TERMS

polar molecule
cohesion
hydrogen bond
solution
solvent
dispersal medium

ANSWERS TO CHECK YOUR FACTS

1. Covalent bonds.
2. No, the electrons are attracted more by the oxygen atom.
3. A molecule that has a positive and a negative pole.
4. The attraction of like molecules to each other.
5. A hydrogen bond.
6. Sugar molecules are evenly distributed throughout the solution and are hydrogen-bonded to water molecules. The solute is the sugar, and the solvent is the water.
7. The physical force of a current of water will carry entire molecules.

MAIN IDEA

The carbohydrates make up one major group of organic compounds that are found in organisms.

MAIN IDEA

Monosaccharides are the subunits of carbohydrates. They all have the same molecular formula but with different arrangements of atoms. The three common monosaccharides are glucose, fructose, and galactose.

SCIENCE BACKGROUND

The general formula for a monosaccharide is $n(\text{CH}_2\text{O})_n$. The name *carbohydrate* means "carbon plus water," derived from the general formula.

CHECK YOUR FACTS

1. Describe the type of bonds that hold the water molecule together?
2. Are electrons shared equally between the oxygen and hydrogen atoms of a water molecule?
3. What is a polar molecule?
4. What is cohesion?
5. The weak type of bonding found between water molecules is an example of what kind of bond?
6. Describe a sugar-water solution. What is the solute and what is the solvent?
7. How can water disperse nonpolar molecules in an organism?

Carbohydrates

3-13 Carbohydrates are organic compounds

The carbohydrates are one major group of compounds found in organisms. They are classified as **organic** (ôr gan'ik) **compounds**. Organic compounds are usually defined as compounds that contain the element carbon. Most compounds in organisms are organic compounds. Water and some of the minerals in bone are the main exceptions. They do not contain carbon and belong to the other main group of compounds called **inorganic** (in ôr gan'ik) **compounds**.

3-14 Monosaccharides The simplest subgroup of carbohydrates in organisms are the **monosaccharides** (mon ə sak'ə rīdz), which are commonly called single sugars. The single sugars all have the molecular formula $\text{C}_6\text{H}_{12}\text{O}_6$. However, they all have a slightly different structural formula. Note in Figure 3-7 that there is a slight difference in the way the individual oxygen and hydrogen atoms are linked together.

The most important single sugar is **glucose** (glü'kōs) (also called **dextrose**). Glucose is found in the blood and in all cells. Think of glucose as having the same function as gasoline in automobiles. Glucose is the number one source of energy for practically all organisms.

The other single sugars commonly found in organisms are **fructose** and **galactose**. Fructose has the sweetest taste of all sugars. It is found in some fruit juices, honey, and the nectar of some flowers. Galactose is rarely found as a single sugar. It is most commonly found combined with glucose in milk sugar.

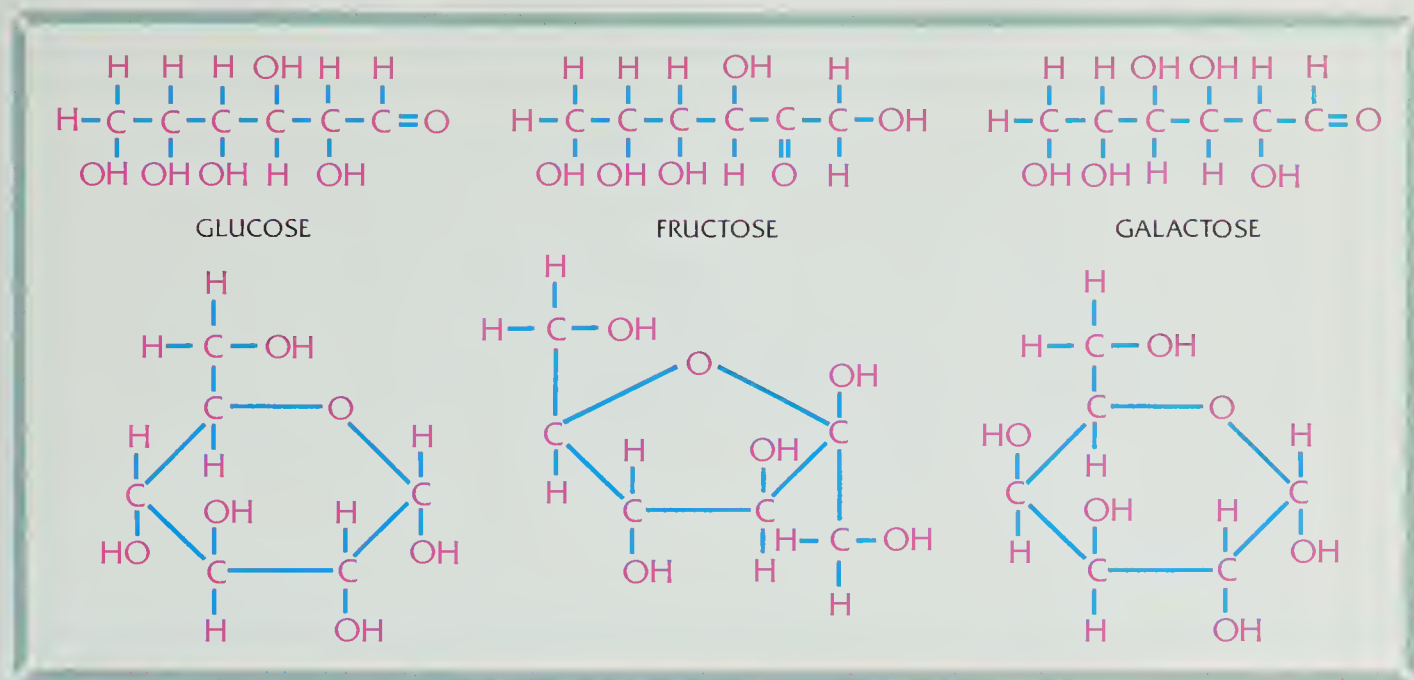
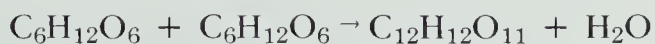


FIGURE 3-7 The structural formulas of three single sugars—glucose, fructose, and galactose

3-15 Disaccharides The **disaccharides** (dī sak'ə rīdz) make up another subgroup of carbohydrates. They are commonly called double sugars. There are three common double sugars and they each have the same molecular formula, which is $\text{C}_{12}\text{H}_{22}\text{O}_{11}$.

Each double sugar is a compound made up of two single sugars. The chemical reaction that joins them is called **dehydration** (dē hī drā'shən) **synthesis**. This name literally means “putting together by the removal of water.” The reaction is shown below.



The opposite reaction, which occurs when organisms break down double sugars into single sugars, is called **hydrolysis** (hī drol'ə sis). This name means “splitting with water.”

The most common double sugar is **sucrose**, which is the cane sugar or beet sugar used in the home. Sucrose is a combination of fructose and glucose. The fructose causes sucrose to be the sweetest of the double sugars.

The other two double sugars commonly found in organisms are **maltose** and **lactose**. Maltose, or malt sugar, is found in seeds that have started to grow, or germinate. It is a combination of two glucose molecules. Lactose, called milk sugar, is present in the milk of different animals. Lactose is a combination of galactose and glucose.

MAIN IDEA

Disaccharides are made up of two monosaccharides that have been linked by dehydration synthesis. Three disaccharides are sucrose, maltose, and lactose.

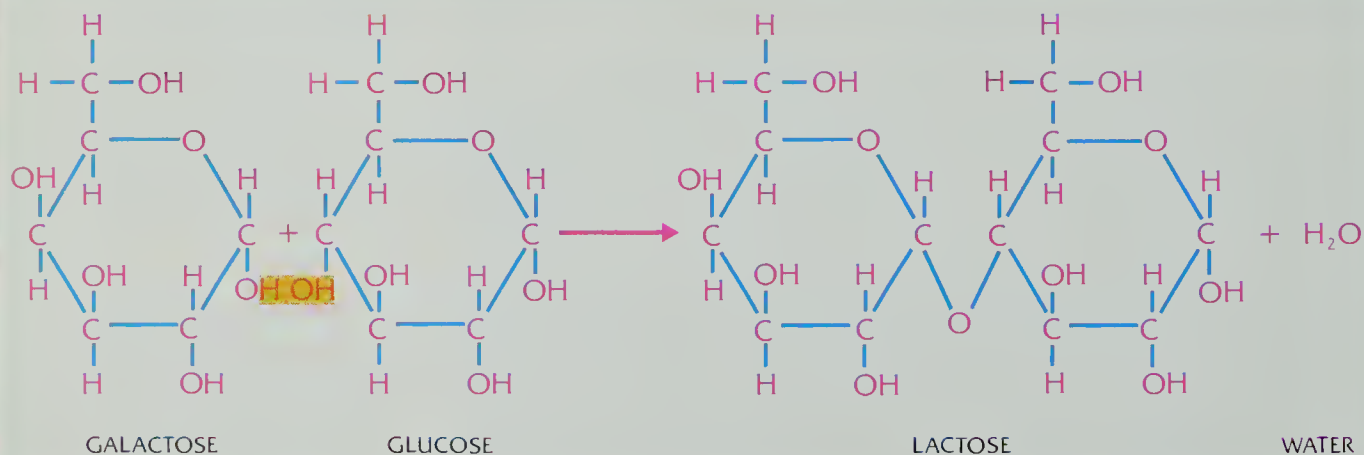
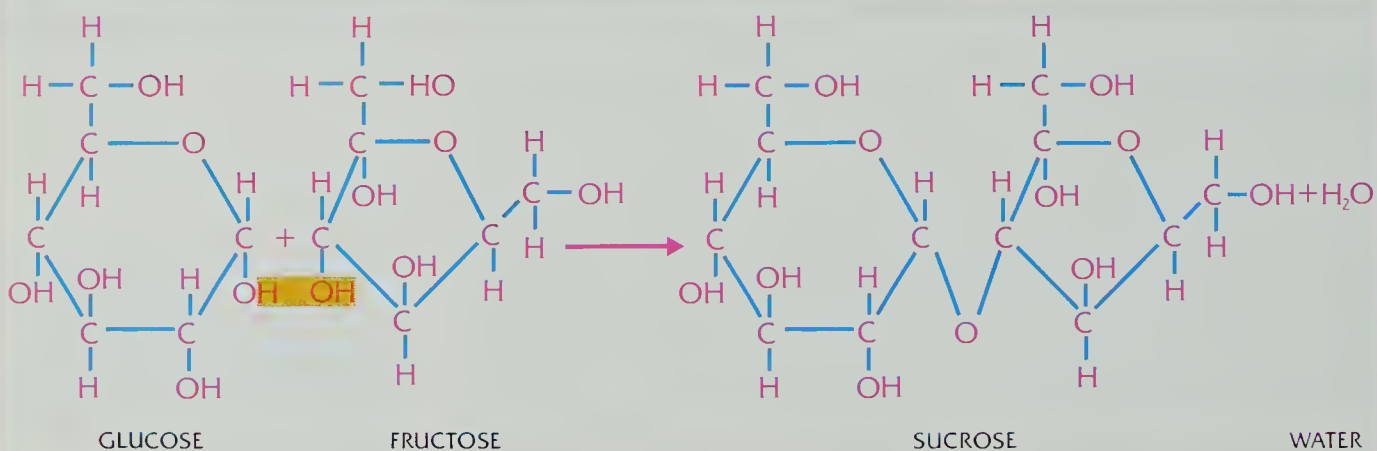
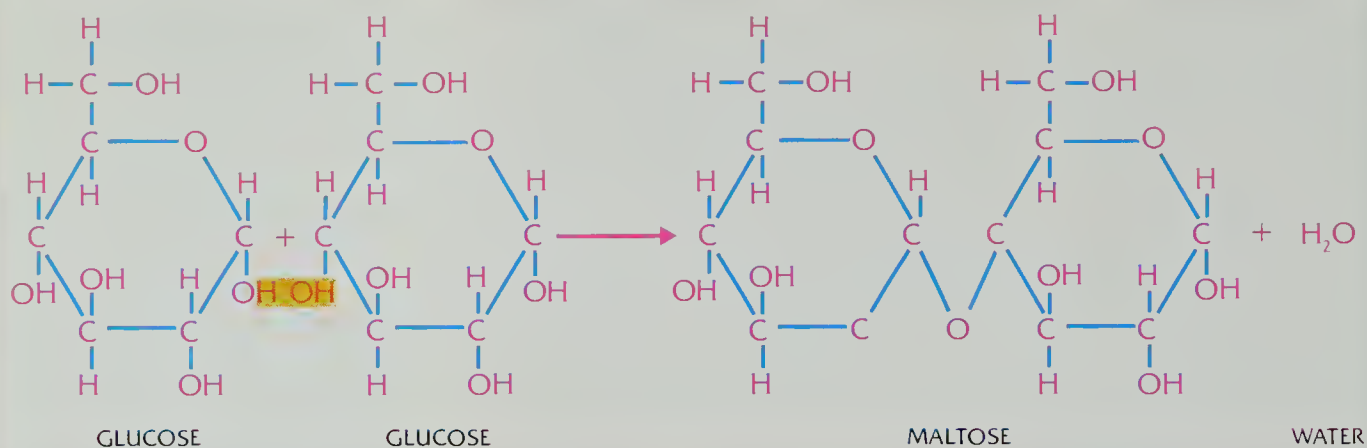


FIGURE 3-8 The structural formulas of three double sugars—sucrose, lactose, and maltose

Some persons are allergic to milk. Sometimes this is caused by an inherited inability to digest the galactose portion of milk sugar. Such a person experiences intestinal cramps and diarrhea after drinking milk.

3–16 Polysaccharides The largest carbohydrate molecules are the **polysaccharides** (pol ē sak'ə rīdz). They are sometimes called compound sugars. The polysaccharides are chains of single sugars linked together by a series of dehydration synthesis reactions. Some compound sugars are long single chains like a string of boxcars in a freight train. Other compound sugars consist of branching chains.

It is impossible to give the molecular formula for a compound sugar because the number of subunits always varies. However, a general formula is written $(C_6H_{10}O_5)_x$ with the x representing a variable number of single sugars.

Starch is one of the most common of the compound sugars. Starch is manufactured in plants by linking together long chains of glucose molecules. Starch is a food-storage molecule for plants. It is much more stable than single or double sugars.

Glycogen (glī'kə jən) is another compound sugar. It is manufactured by animals and is sometimes called animal starch. Glycogen also is a storage molecule that is made up of glucose subunits. However, the chains of glycogen are much more highly branched than the chains of starch. Glycogen is stored in your liver and muscles. When energy is needed by your body, the glycogen is hydrolyzed into individual glucose molecules, which are then used for energy.

The most common of the compound sugars is **cellulose** (sel'yə lōs). Cellulose is the main structural material in plant cell walls. Cotton, wood, and wood products, such as paper, are common materials made up almost entirely of cellulose.

Cellulose is made up of long chains of glucose subunits. However, the bonds linking the glucose subunits are not easily broken. Because of this fact, cellulose is not easily digested as are starch and glycogen. Some animals, such as cows, horses, goats, and termites, do digest cellulose in wood and other plant material. However, the actual digestion is done by microorganisms that live in their digestive systems. Years ago a classic experiment demonstrated this unique relationship. Termites were heated to a temperature that killed their internal microorganisms but not the termites themselves. Later the termites died of starvation, even when surrounded with wood, their favorite food.

SCIENCE TERMS

organic compounds
inorganic compounds
monosaccharides
glucose
fructose
galactose
disaccharides
dehydration synthesis
hydrolysis
sucrose
maltose
lactose
polysaccharides
starch
glycogen
cellulose

MAIN IDEA

Polysaccharides are chainlike compound sugars made up of monosaccharides. Starch and glycogen are energy-storage molecules. Cellulose, is the main structural molecule in cell walls and is the main ingredient in wood, paper, and cotton.

Cotton fibers are made up almost entirely of cellulose.



ANSWERS TO CHECK YOUR FACTS

1. Carbon.
2. Glucose serves as the main source of energy for most organisms.
3. The chemical reaction that removes a molecule of water when two molecules are joined.
4. Hydrolysis.
5. Sucrose: in the home as table sugar; lactose: in milk, maltose: in seeds.
6. Starch, glycogen, and in some cases cellulose.
7. Because the bonds in cellulose are not broken easily.
8. Starch and cellulose.

MAIN IDEA

Fats are the most efficient energy-storage molecules in organisms and are constantly being used and replaced.

SCIENCE BACKGROUND

Fats belong to a large group of organic molecules called lipids. The lipids also include waxes, terpenes, and steroids, the latter including several different hormones and vitamin D. All lipids tend to be insoluble in water but soluble in organic solvents.

CHECK YOUR FACTS

1. What element do organic compounds have in common?
2. Why is the single sugar glucose important?
3. What is dehydration synthesis?
4. What is the reaction called when water is added to break down a molecule such as a double sugar?
5. Name three common double sugars and tell where they can be found.
6. Name two important polysaccharides used for energy storage in organisms.
7. Explain why many organisms are unable to digest cellulose.
8. Which of the following carbohydrates are found in plants: glycogen, starch, and cellulose?

Fats

3–17 The energy function Fats serve two main functions in organisms. One function is energy storage. We already have described how single sugars can be stored in larger molecules of starch and glycogen. An even more efficient way for plants and animals to store energy is to convert sugars and starches to fats. On the average, 1 g of fat will provide an organism with more than twice the energy of a gram of any carbohydrate.

Plants use fats to store energy only to a limited degree. Most plant fats are found in seeds, where a more concentrated source of energy is useful. Peanut oil, soybean oil, and cottonseed oil are examples of fats that are produced from plant seeds.

Most animals have a weight problem because they must be mobile to survive. (Flying animals, such as birds, have a very serious weight problem.) Nature has solved this weight problem by giving animals the ability to convert starches and sugars into fats. The fats take up less space and provide the same energy with less than half the weight of glycogen.

In modern society, farmers make use of the animal's ability to convert starches to fat. They fatten hogs and steers by feeding them grains with a high starch content. The animals hydrolyze the starch and use some of the glucose for energy. But most of it is converted to fat and stored in the body. The same thing often happens to us when we eat fattening foods, such as candy. Candy contains little or no fat, but it does contain a lot of carbohydrates that our bodies will convert to fat.



Hogs hydrolyze the starch in corn and use some of the glucose for energy.

It is common for people to think that fats are stored in the animal body and used only for energy when food is not available. That is not correct. Fats are constantly being used and replaced. Studies with mice have shown that about half their stored fats are used up and replaced every week.

3–18 *The structural function* Fats and fatlike compounds also have an important structural function in organisms. An example is the fatlike compounds that make up the middle portion of the plasma membrane. This is the membrane that encloses the cell and helps control the movement of materials in and out of the cell. Fatlike compounds also are an important structural material surrounding nerve fibers, which branch throughout the bodies of most animals.

MAIN IDEA

Fats and fatlike compounds have an important structural role in organisms.

A layer of fat also has a structural function under the skin of many animals. Such under-the-skin fat is called **subcutaneous** (sub kyü tã'nē əs) **fat**. Subcutaneous fat helps insulate the animal body and prevent heat loss. In warm-blooded aquatic animals, such as the whale and seal, the subcutaneous fat is very thick and is called blubber. Subcutaneous fat also serves a protective function by cushioning the different parts of the animal body. The pads of a dog's feet are cushioned by fat and protect the underlying bones. Another example is the subcutaneous fat under the inside of our hands. This fat protects the hand bones from physical blows, such as those received from catching a baseball.

MAIN IDEA

Fats are made up of glycerol and fatty acids. Unsaturated fatty acids have one or more double bonds in their carbon skeleton and are usually liquid at room temperature. Saturated fats have no double bonds in their carbon skeleton and are solid at room temperature.

SCIENCE BACKGROUND

Triglycerides can be hydrolyzed back to glycerol and the fatty acids by a technique used in rural communities years ago. The triglycerides of animal fat were boiled in lye, which is sodium hydroxide. After hydroxylation, the sodium combined with the free fatty acids to make soap, called lye soap, which was used for all basic household cleaning.

SCIENCE TERMS

subcutaneous fat
glycerol
fatty acid
triglyceride
unsaturated fatty acid
double bonds
saturated fatty acid
hydrogenation

3–19 The structure of fats The fats are made up of two basic kinds of molecules. One molecule is **glycerol** (glis'ə rōl). The other is the **fatty acid**. A complete fat, called a **triglyceride** (trī glis'ə rīd), consists of one glycerol molecule bonded to three fatty acid molecules. Note in Figure 3–9 how fats are formed by dehydration synthesis and broken down by hydrolysis.

There are two types of fatty acids that may be found in fats. One type is the **unsaturated** (un sach'ə rā tid) **fatty acid**. The unsaturated fatty acid has one or more **double bonds** in the carbon skeleton of the molecule. A double bond is a covalent bond where two electrons are being shared by each adjoining atom. (The double bond is diagramed in a structural formula by two dashed lines.) An example of an unsaturated fatty acid is oleic acid, which is in the fats of peanut oil and olive oil.

The other type of fatty acid is called a **saturated** (sach'ə rā tid) **fatty acid**. An example is stearic acid, which is in beef fat. Saturated fatty acids have no double bonds in the carbon skeleton of the molecule. Each carbon atom in the chain (except the end carbon) is completely surrounded by hydrogen atoms.

Saturated fats are made up of saturated fatty acids. Saturated fats are solid at room temperature. Unsaturated fats are made up of unsaturated fatty acids. They are usually liquid at room temperature and are called oils. As a general rule, animal fats are saturated fats and plant fats are unsaturated. However, through a technique called **hydrogenation** (hī drə jə nā'shən), hydrogen atoms can be added to fatty acid chains in unsaturated fats. This eliminates the double bonds and converts unsaturated plant oils into solid saturated fats. This is the process used to convert cottonseed oil and soybean oil into margarine, a butter substitute.

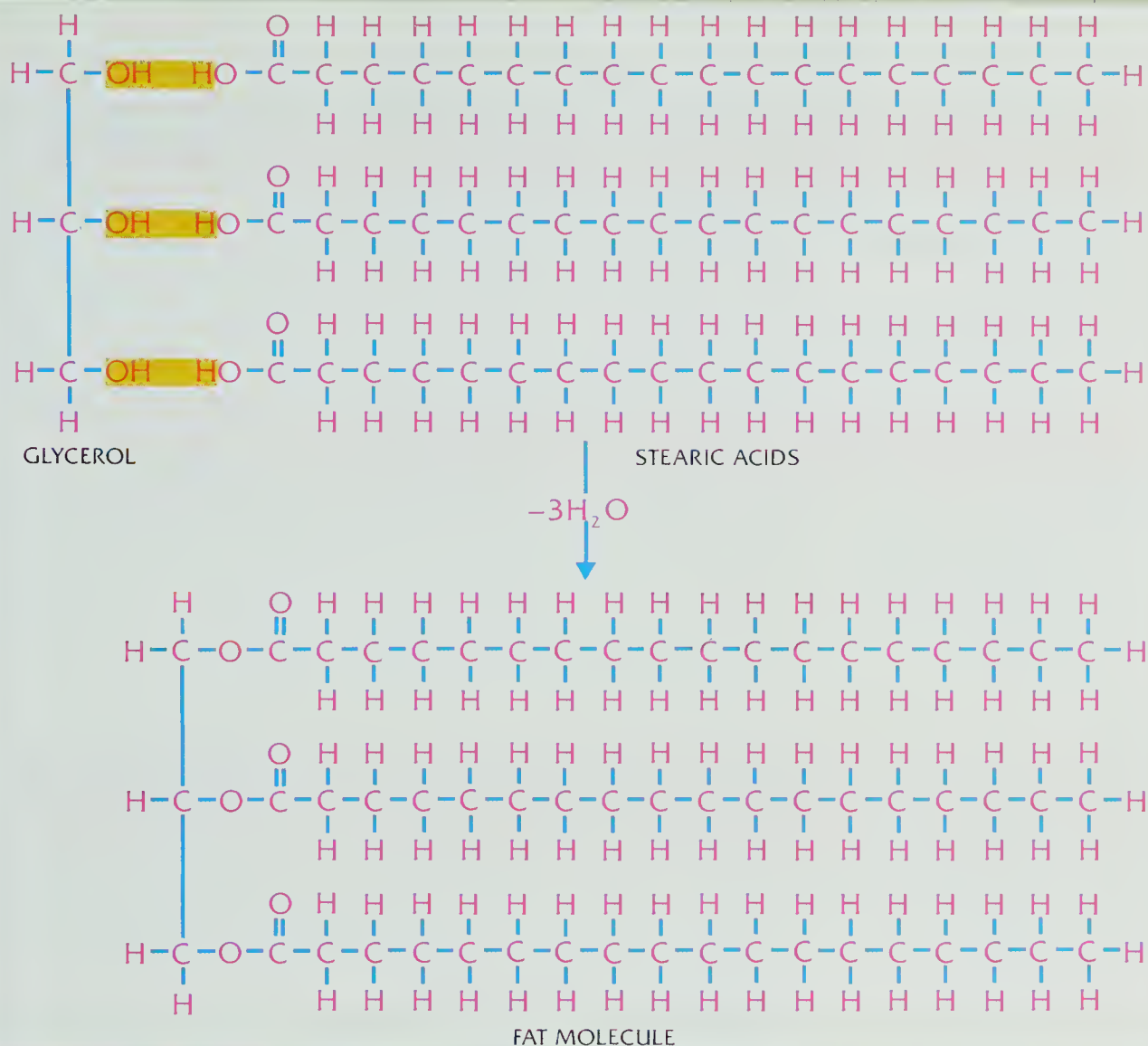


FIGURE 3-9 Diagram of a fat molecule. A complete fat is made up of one glycerol molecule bonded to three fatty acid molecules.

CHECK YOUR FACTS

1. What are two important functions of fats in an organism?
2. Why is the ability to convert carbohydrates to fats important in mobile animals?
3. What is subcutaneous fat?
4. Name two functions of subcutaneous fat.
5. What two kinds of molecules make up fats?
6. What is an unsaturated fatty acid?
7. Are saturated fats solid at room temperature?
8. What type of fat is found in plants?

ANSWERS TO CHECK YOUR FACTS

1. Energy storage and structural material.
2. Fats allow them to reduce the amount of body weight needed for energy storage.
3. A layer of fat found under the skin of many animals.
4. It can help insulate against heat loss and serve as protective padding.
5. Glycerol and fatty acids.
6. A fatty acid that has at least one double bond in its structure.
7. Yes.
8. Unsaturated fats, or oils.

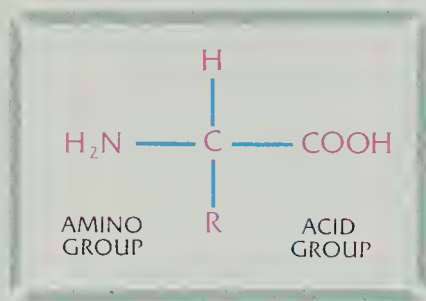


FIGURE 3-10

The general formula for an amino acid

MAIN IDEA

Proteins are generally very large, complex molecules that have been extremely difficult to study in past years.

MAIN IDEA

Proteins are all made up of 20 different amino acids linked together in chains. The amino acids are all alike except for the R groups, which differ in each amino acid.

SCIENCE BACKGROUND

Besides the basic 20 amino acids, there are a number of others that are present in small amounts in different organisms. But if they are in a protein, they are derived from the basic 20. An example of a derived amino acid is the hormone thyroxine, which is synthesized from tyrosines in the thyroid protein, thyroglobulin.

Proteins

3-20 Giant molecules If all the water were removed from cells, most of the remaining matter would be made up of **proteins**. Proteins are the second most abundant compounds in cells.

Most proteins are giant molecules. Many are thousands of times larger than carbohydrates and fats. Over the years their large size created problems for biologists who tried to understand their functions in organisms. The proteins were so large nobody could determine their structure. Without knowledge of their structure, it was impossible to determine their exact function.

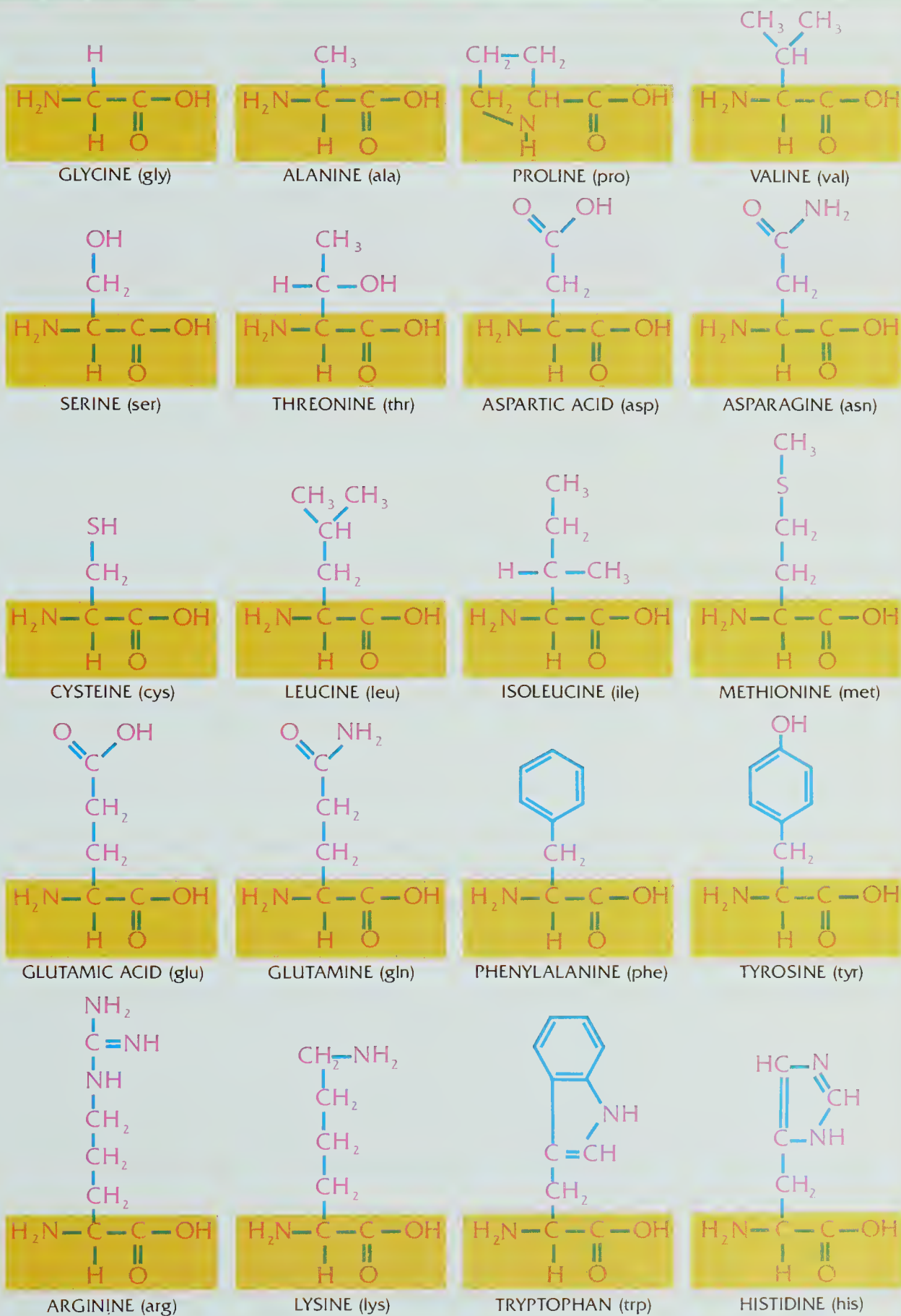
Within the past two decades, biologists have learned much about the structure of a few proteins. Even though the structure of hundreds of thousands of other proteins is unknown, enough general knowledge is available to clarify their role in organisms. For example, we now know that a slight change in the structure of one body protein may be enough to cause a serious disease.

3-21 The basic structural subunits All proteins are made up of subunits linked together like the cars of a freight train. The individual subunits are called **amino** (ə mē'nō) **acids**. Each amino acid is made up of carbon, hydrogen, and oxygen—as are the carbohydrates and fats. However, there is one additional element present in amino acids that is not found in carbohydrates or fats. This is the element nitrogen.

There are 20 different amino acids that make up most proteins, but they all have certain things in common. Note the generalized structural formula for an amino acid in Figure 3-10. Note that each amino acid has one carbon called the alpha carbon. The alpha carbon always is bonded to one NH_2 group, which is called an amino group. Also bonded to the alpha carbon is another group called an acid group. This leaves two bonds. One is always linked to a hydrogen atom and the other to a variable group called an R group.

It is the R group that is different in each of the 20 different amino acids. The simplest amino acid, called glycine, has only one hydrogen atom making up the R group. In Figure 3-12 compare glycine with **alanine**, **lysine**, and **cysteine**, which are three other amino acids with more complex R groups.

FIGURE 3-11 The 20 amino acids



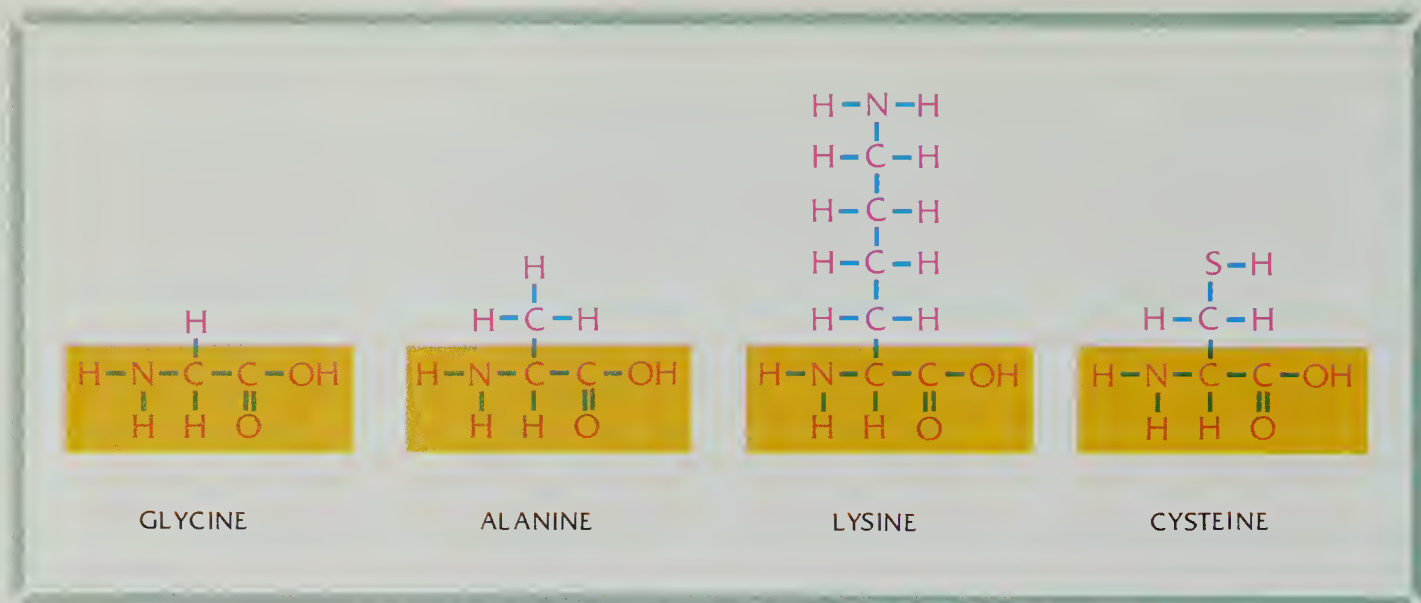


FIGURE 3-12 Glycine, alanine, lysine, and cysteine are simple amino acids with varying R groups.

MAIN IDEA

Every protein or polypeptide has a specific amino acid sequence that is called the primary structure. The amino acids are linked by peptide bonds.

3-22 Primary structure Earlier, proteins were compared to freight trains that are made up of freight cars linked together. This comparison can be continued to further explain protein structure.

The typical freight train is made up of a hundred or more freight cars linked together. However, seldom is a freight train made up of *only one* kind of freight car. Usually it is made up of a variety of freight cars, such as boxcars, coal cars, tank cars, refrigerator cars, automobile-transport cars, and so on. In any freight train the sequence of the different cars will vary. There may be three boxcars in a sequence, followed by eight tank cars and one coal car. It is unlikely that any two freight trains will ever have exactly the same sequence.

In many ways proteins can be compared to freight trains. Just substitute the 20 different amino acids for the different kinds of freight cars. Proteins are made up of different amino acids linked together. And proteins differ in the sequence of amino acids. The different amino acids may appear in any order, and any one may be used several times within one protein. The big difference is in numbers. Freight trains only have a hundred or so freight cars. Most proteins have several hundred or thousands of amino acids.

Every different protein has a different sequence of amino acids. This sequence is called the **primary structure** of a protein. The primary structure results when amino acids react by dehydration synthesis. The amino group of one amino acid becomes bonded to the acid group of another

amino acid, and one water molecule is released. The resulting bond between the two amino acids is a covalent bond with a special name. It is called a **peptide** (pep'tīd) **bond**. Usually one chain of amino acids linked together is called a **polypeptide** (pōl ē pep' tīd) **chain**, or more simply, a polypeptide.

3-23 A complex structure Protein molecules are not long, straight chains like a freight train. Most proteins are made up of two or more polypeptides. The polypeptides are usually coiled, twisted, and folded around each other and look somewhat like a tangled rope.

After amino acids become linked together, the polypeptide usually shrinks in length and becomes coiled. This is the result of hydrogen bonding between amino and acid groups of adjacent amino acids.

A second type of structural change also occurs. The different R groups begin to react with each other. Some are attracted to each other by relatively weak hydrogen bonds. Others form ionic bonds or the much stronger covalent bonds. The reaction of the R groups causes the chain to fold and twist into a unique three-dimensional shape.

A third type of structural change may occur as the polypeptides are folding and twisting. One polypeptide chain may unite with another chain or chains. This greatly complicates the folding and twisting process because of the interaction by all the different R groups.

Many proteins are fragile molecules that can have their three-dimensional structure permanently changed, or **denatured** (dē nā'chərd). The white of a hen's egg, which is largely a protein called albumin, is an example of a fragile protein. Like many proteins, it is very sensitive to heat. Heat the albumin and it changes from a clear jellylike protein into a harder white substance. No chemical

SCIENCE BACKGROUND

Other terms used to describe amino acid chains are *dipeptide* (2 amino acids), *tripeptide* (3 amino acids).

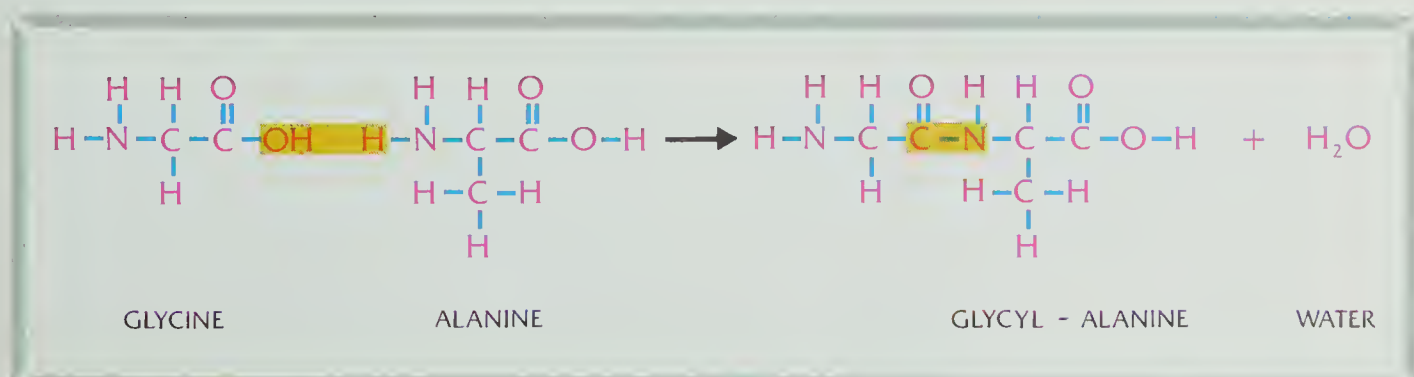
MAIN IDEA

Most proteins are made up of two or more polypeptides that have a specific three-dimensional shape. The protein is coiled, folded, and twisted because of different kinds of bonding between R groups and other attractive forces within the molecules.

SCIENCE BACKGROUND

Beyond their primary structure, proteins exhibit secondary, tertiary, and quaternary structure. *Secondary structure* results from hydrogen bonds between the oxygen of one peptide group and the nitrogen of another. *Tertiary structure* is the way that regions of secondary structure are oriented with each other, and this is dependent upon reactions of the R groups, or "side chains." The only covalent bond is between sulfur atoms present in two cysteines. The *quaternary structure* is the spatial arrangement of the polypeptide chains that are the subunits of most proteins.

FIGURE 3-13 Amino acids bond together in dehydration synthesis, forming a molecule of water. This bond is called a peptide bond and denotes peptide formation.



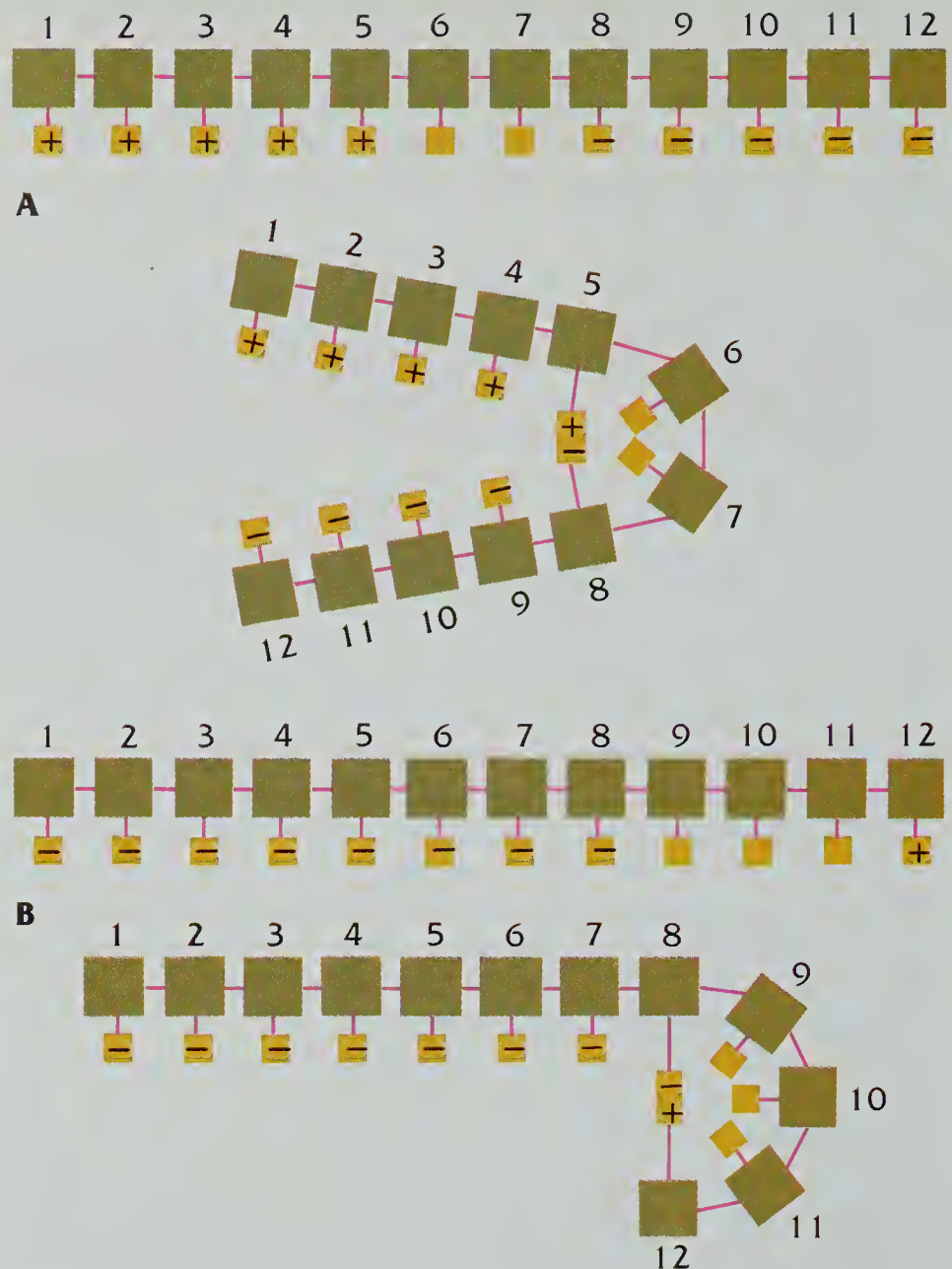


FIGURE 3–14 A protein chain of amino acids can twist and bend in a variety of ways because certain amino acids bond with each other.

process can reverse this reaction. Many human proteins also are sensitive to heat. This is one reason why very high fevers can be so dangerous.

MAIN IDEA

The primary structure is extremely important because it determines the overall three-dimensional shape of the molecule.

3–24 The primary structure is extremely important Observe the two diagrams in Figure 3–14. Note the primary structure of each polypeptide, which, for simplicity, has been labeled with numbers rather than with the names of amino acids. Note in the A chain that there is an attraction between the R groups of amino acid number 8 and number 5. This causes the polypeptide to form a loop near one end.

Now observe the chain in diagram B and note what happens when amino acid number 8 is in a different sequence. The structure of chain B has an entirely different shape.

The diagrams in Figure 3–14 help demonstrate a very important fact about proteins. *The primary structure largely determines the overall three-dimensional shape of the molecule.* In turn the three-dimensional shape of the protein molecule determines how it will function. Let us see why that is so important.

3–25 Protein structure and sickle-cell anemia Sickle-cell anemia is a genetic disease, which means that it is inherited. The disease is caused by an abnormal protein that is found in red blood cells.

The red blood cells carry oxygen from the lungs to all parts of the body. Inside each red blood cell are more than 200 million protein molecules called **hemoglobin**. The hemoglobin molecules are the oxygen carriers.

Each hemoglobin molecule is made up of four polypeptide chains, each with about 150 amino acids. Two of the chains, called alpha chains, have the same primary structure. The other two chains, called beta chains, have a different primary structure. Altogether the hemoglobin molecule has 600 amino acids, which is quite a small protein.

About two decades ago scientists began to study the primary structure and three-dimensional shape of hemoglobin. They compared the structure of normal hemoglobin and hemoglobin from persons with sickle-cell anemia.

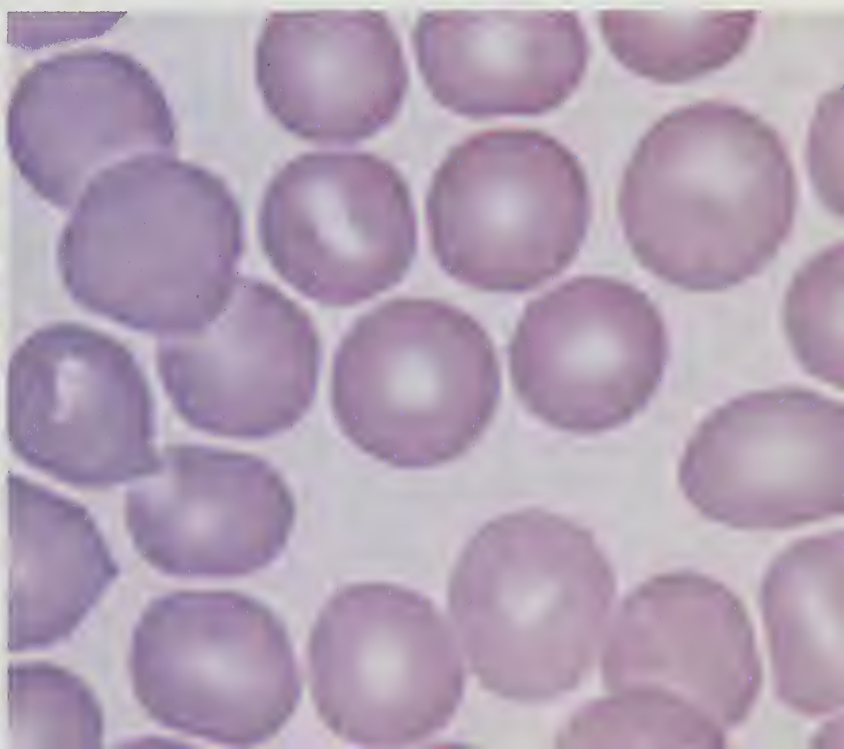
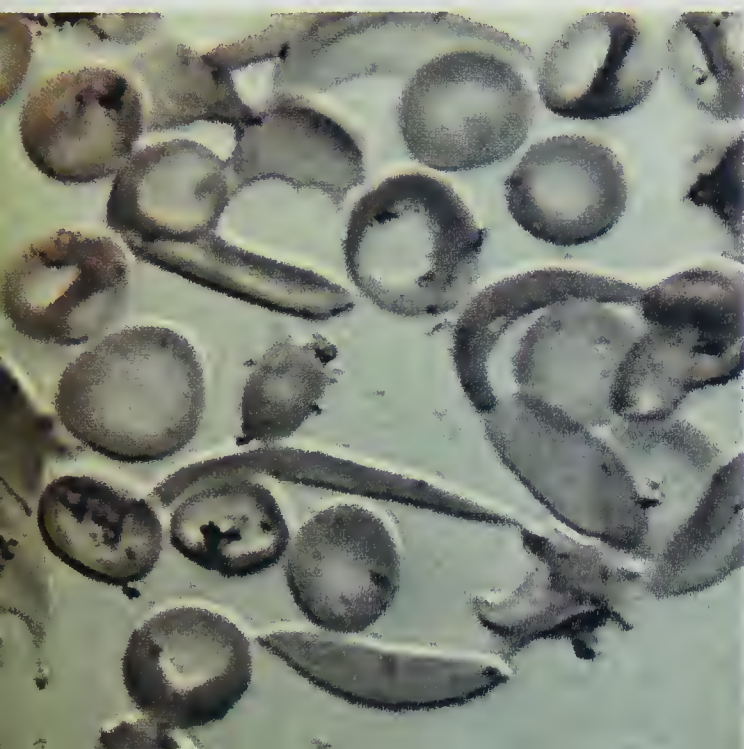
MAIN IDEA

The substitution of one amino acid in two of the four chains of hemoglobin is enough to cause the disease sickle-cell anemia. This illustrates the extreme importance of the primary structure in determining the three-dimensional shape that will function properly.

SCIENCE BACKGROUND

It should be strongly emphasized that the primary structure determines the three-dimensional shape of proteins and, in turn, their function. This is the basis for understanding the role of DNA in the cell. DNA contains the codes for the primary structure of all proteins.

Normal red blood cells (right) and sickle cells (left).



SCIENCE TERMS

proteins
amino acids
glycine
alanine
lysine
cysteine
primary structure
peptide bond
polypeptide chain
denatured
hemoglobin

MAIN IDEA

Proteins are formed by the assembly of amino acids in a specifically designated order.

ANSWERS TO CHECK YOUR FACTS

1. Nitrogen.
2. Proteins are made of amino acid subunits.
3. Protein molecules are extremely large and complex.
4. The part of an amino acid that is unique to that type of amino acid.
5. A covalent bond between amino acids.
6. Between R groups.
7. A protein whose three-dimensional structure has been permanently changed.
8. The primary structures of the polypeptide chains in the molecule.
9. A different amino acid in sequence will cause different bonding patterns and thus a different shape.

ANSWERS TO REVIEW QUESTIONS

1. Carbon, oxygen, hydrogen, and nitrogen.
2. Ions have more or fewer electrons than their atomic number and thus are charged.

Their studies showed that the primary structure of the alpha chains in the two hemoglobins was exactly the same. But in the beta chains there was one very small difference. In normal hemoglobin, position number six of the beta chain has an amino acid called glutamic acid. The beta chain of abnormal hemoglobin has the amino acid valine in the sixth position.

In the case of hemoglobin just 2 different amino acids out of 600 are enough to change the three-dimensional shape of the molecule. In turn this can cause some red blood cells to become sickle-shaped. Such cells can plug small blood vessels like a log jam in a river. This prevents normal blood cells from carrying oxygen.

3–26 How do the right amino acids get lined up? There are 100 000 or more different proteins in the cells of most plants and animals. The typical protein probably averages well over 1 000 amino acids in all its chains. We have seen, with the example of sickle-cell anemia, the extreme importance of primary structure in the overall shape and function of a protein. These facts lead us to an important question. How can a cell, which builds all the different proteins, line up the millions of amino acids in the right order so that each protein will function properly? To do so a cell would need something like a book of instructions that would list the primary structure for each protein. Also the cell would need some kind of precision assembly plant where all the amino acids would be linked together according to the instructions for each protein.

Where in the cell is the “book of instructions”? And where is the “assembly plant”? These questions will be answered in the next chapter.

CHECK YOUR FACTS

1. What element is not found in fats or carbohydrates but is found in proteins?
2. How are proteins and amino acids related?
3. Why has the protein molecule been so difficult to analyze and understand?
4. What is meant by the term *R group*?
5. What is a peptide bond?
6. Where are ionic bonds found in polypeptides?
7. What is a denatured protein?
8. What determines the shape of a protein molecule?
9. Why can a single change in the primary structure affect the function of the protein?

SUMMARY

Matter is made up of particles called atoms. There are 92 naturally occurring types of atoms or elements. Of these 92, the four elements carbon, oxygen, nitrogen, and hydrogen make up nearly all living matter. Atoms bond with each other in various ways to form molecules.

Water is the most abundant inorganic molecule found in living matter. Because of the bonding arrangement within the water molecule, it has polar characteristics. This polarity enables water to act as an excellent solvent.

Carbohydrates are a group of organic molecules that are important in energy storage and structural support. The structural subunits of carbohydrates are the simple sugars, such as glucose and fructose.

Fats store energy more efficiently than carbohydrates, a fact that makes fats much more vital to mobile animals than to plants.

REVIEW QUESTIONS

1. What are the four most common elements found in living matter?
2. Explain the difference between ions and isotopes.
3. Describe ionic, covalent, peptide, and hydrogen bonding. Which is weakest?
4. How do elements differ from compounds?
5. Why can water act as a good solvent?
6. What are the subunits of polysaccharides? Of polypeptides? Of fats?
7. Describe dehydration synthesis.
8. What are some differences in the carbohydrate and fat composition of plants compared with that of animals?
9. How many amino acids are there, and how do they differ in structure?
10. Sickle-cell anemia is caused by a protein with an abnormal primary structure. Explain.

ANALYSIS AND APPLICATION

1. As heat is applied to a protein, denaturing starts to occur. What type of bonds are probably being broken? Explain.
2. The mass number of an atom is 67 and it contains 37 neutrons. A second atom has 31 electrons and a mass number of 66. Both atoms are of the same element. What is their atomic number? How can they possibly be the same element?

Isotopes of an element have varying amounts of neutrons and different atomic masses.

3. Ionic bonding is an attraction between oppositely charged ions. Covalent bonding is a sharing of electrons between atoms. A peptide bond is a covalent bond between amino acids. Hydrogen bonds form between polar molecules. Hydrogen bonds are weakest.

4. An element contains only one type of atom. Compounds contain two or more types of atoms.

5. Water is a polar liquid.

6. Monosaccharides, or single sugars. Amino acids. Glycerol and fatty acids.

7. An OH group from one molecule combines with an H from another to form one water molecule and a covalent bond between the two molecules.

8. Plants contain starch and cellulose but not glycogen. The fats in plants are generally unsaturated. The opposite holds true for animals.

9. Twenty. They each have a unique R group.

10. A change in the amino acid sequence, or primary structure, causes hemoglobin to change its shape. This reduces the molecule's ability to function properly.

ANSWERS TO ANALYSIS AND APPLICATION

1. The hydrogen bonds between the amino and acid groups will be easiest to break.
2. Thirty. The first atom must have 30 protons ($67 - 37 = 30$). The second atom has one less neutron and one more electron. It has to be another isotope and it must be a negative ion.

Investigations 8–9 from *Laboratory Investigations in Biology*
can be done with this chapter

4 *DNA and Protein*



SCIENCE BACKGROUND

It is strongly recommended that all teachers and interested students read *The Double Helix*, by James Watson (New York: Atheneum, 1968); this is also in paperback.

OBJECTIVES

- To know that DNA carries a code that specifies the primary structure for all proteins in the body of an organism
- To understand the Watson-Crick model for base-

pairing and replication in the DNA molecule

- To explain how the DNA code is read by messenger RNA
- To understand how the transfer RNA and the ribosomes team up to synthesize polypeptide chains according to the code specified by a section of DNA
- To appreciate how mutations can occur in genes
- To understand genetic engineering

Synthesis

Structure of DNA

4-1 The instructions In the last chapter we said that a cell must have something similar to a book of instructions for making proteins. The instructions must be like recipes for the thousands of proteins that are synthesized, or manufactured, in the cell. These recipes must specify the exact sequence of amino acids, the primary structure of each protein.

In a cell there is a large molecule (or molecules) of **deoxyribonucleic** (dē ok sō rī bō nū klē'ik) **acid** that can be compared to a book of protein recipes. This is better known as DNA.

MAIN IDEA

DNA contains the information that the cell uses to assemble all proteins.

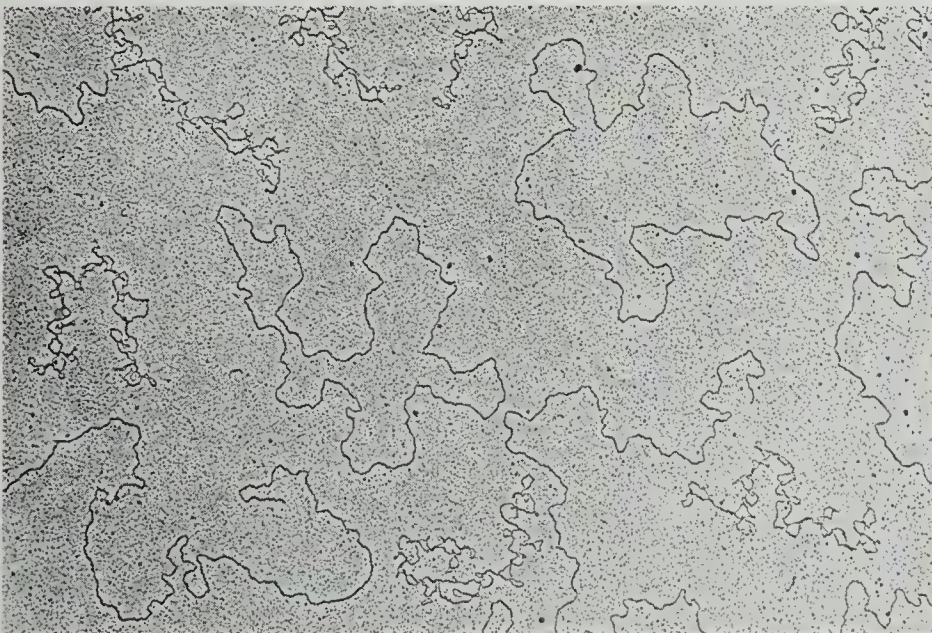
MAIN IDEA (4-2)

In procaryotic cells DNA is found throughout the cell: twisted, coiled, and tightly packed. In eucaryotic cells 98 percent is in the nucleus; 2 percent is in organelles, such as mitochondria and chloroplasts.

MAIN IDEA (4-3)

Watson and Crick developed the present model of the DNA molecule that is widely accepted. The molecule is a double helix made up of four different nucleotides, each with different nitrogen bases that are bonded by weak hydrogen bonds in the center of the molecule.

The twisting lines in the photograph at left are bacterial chromosomes. The DNA molecules of the bacterial cells are in the chromosomes.



HYDROGEN
BOND

PHOSPHATE UNIT

SUGAR UNIT

	
ADENINE	THYMINE
	
GUANINE	CYTOSINE
DOUBLE-RING BASES	SINGLE-RING BASES

FIGURE 4-2

The DNA molecule exists in the form of a double helix. This structure was first proposed by Watson and Crick.

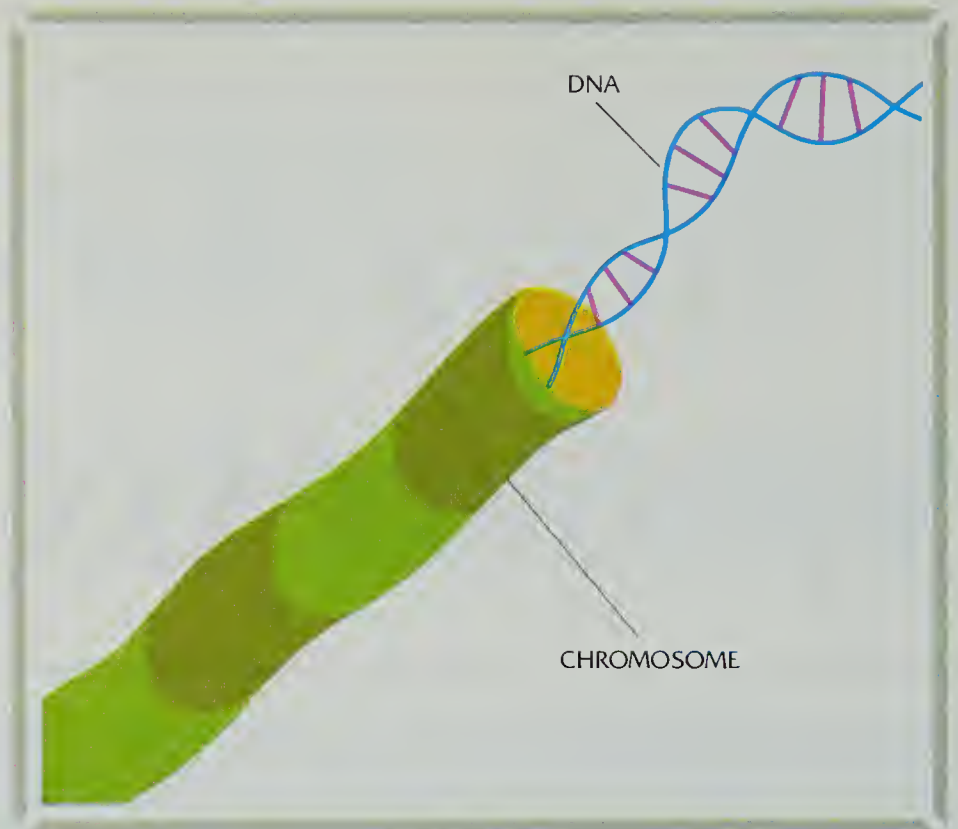


FIGURE 4-1 In eucaryotic cells most of the DNA is tightly packed in chromosomes located in the nucleus.

4-2 Where is the DNA in cells? In procaryotic cells, which are cells without a nucleus, the DNA is found throughout the cells. The DNA molecule is very long, twisted, coiled, and packed tightly inside the cell. In one bacterial cell, named *E. coli*, the DNA molecule is about 1 mm long. This molecule is about 1 000 times longer than the cell itself.

In eucaryotic cells about 98 percent of the DNA is in the nucleus and is called **nuclear** (nū'klē or) **DNA**. The nuclear DNA is in the chromatin material, which condenses and forms the chromosomes that are seen during cell division. There is probably one very long DNA molecule in each of the chromosomes. If this is accurate for all eucaryotic cells, each human body cell, with 46 chromosomes, would contain 46 molecules of DNA.

About 2 percent of the DNA in eucaryotic cells is in organelles such as the mitochondrion and chloroplast. This DNA is called **organelle** (ôr gə nel') **DNA**.

4-3 The Watson-Crick model of DNA In 1953 two scientists, James Watson and Francis Crick, announced a model for the structure of the DNA molecule. Since that

time there has been a tremendous amount of research on DNA. The Watson-Crick model is now widely accepted by scientists.

The overall shape of the DNA molecule is described as a double helix. See Figure 4–2. However, when trying to understand the structure of the molecule, it is helpful to untwist it mentally and imagine it as a long ladder, as shown in Figure 4–3.

The DNA molecule is made up of repeating subunits called **nucleotides** (nü'klē ə tīdz). Each nucleotide is made up of three chemical groups. One is a **phosphate** (fos'fāt) group. The second is a 5-carbon sugar called **deoxyribose** (dē ok sə rī'bōs). The third group is called a **nitrogen** (nī'trə jən) **base**. The phosphate and deoxyribose groups are the same in all the nucleotides. However, there are four different nitrogen bases and therefore four different nucleotides in DNA. The nucleotides are named for the specific nitrogen base they contain. The four different nitrogen bases are called **adenine** (ad'ə nin), **thymine** (thī'min), **guanine** (gwä'nēn), and **cytosine** (sī'tə sin).

In Figure 4–3 you can see how the sides of the ladder are made up only of the phosphate and sugar parts of the nucleotides. The nitrogen bases are found only in the steps of the ladder. Note how the nitrogen bases are bonded to each other in the middle region of the steps. The bonds that link the two nucleotides are hydrogen bonds. Hydrogen bonds are much weaker than all the other bonds in the molecule.

4–4 The DNA base-pairing rule An important part of the Watson-Crick model is the **base-pairing rule**. This rule states that adenine bases are only paired with thymine bases, and that guanine bases are only paired with cytosine bases.

4–5 DNA replication Another part of the Watson-Crick model explains how exact replicas of any DNA molecule can be produced. The process is called **replication** (rep lə kā'shən). In replication the DNA molecule separates, or “unzips,” down the middle of each step where the hydrogen bonds link the two nitrogen bases. Then nucleotides from the cell environment attach themselves to the exposed nitrogen bases. For example, if half the DNA molecule has an exposed thymine nucleotide, an adenine nucleotide from the cell environment will bond to it. And if the other side of the DNA molecule has an exposed guanine nucleotide, a cytosine nucleotide will bond to it.

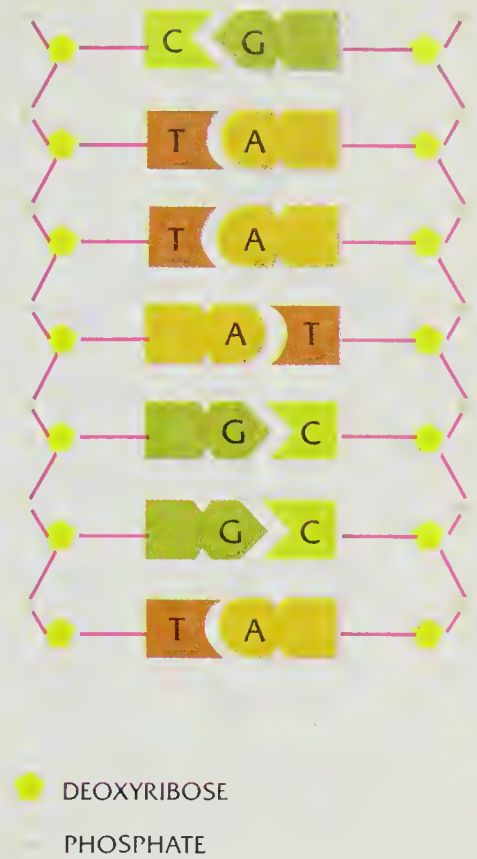


FIGURE 4–3

Alternating units of sugars and phosphates make up the sides of the DNA ladder while nitrogen bases make up the rungs.

MAIN IDEA

The base-pairing rule—adenine bonds only with thymine, guanine bonds only with cytosine.

SCIENCE TERMS

deoxyribonucleic acid
DNA
nuclear DNA
organelle DNA
nucleotides
phosphate
deoxyribose
nitrogen base
adenine
thymine
guanine
cytosine
base-pairing rule
replication

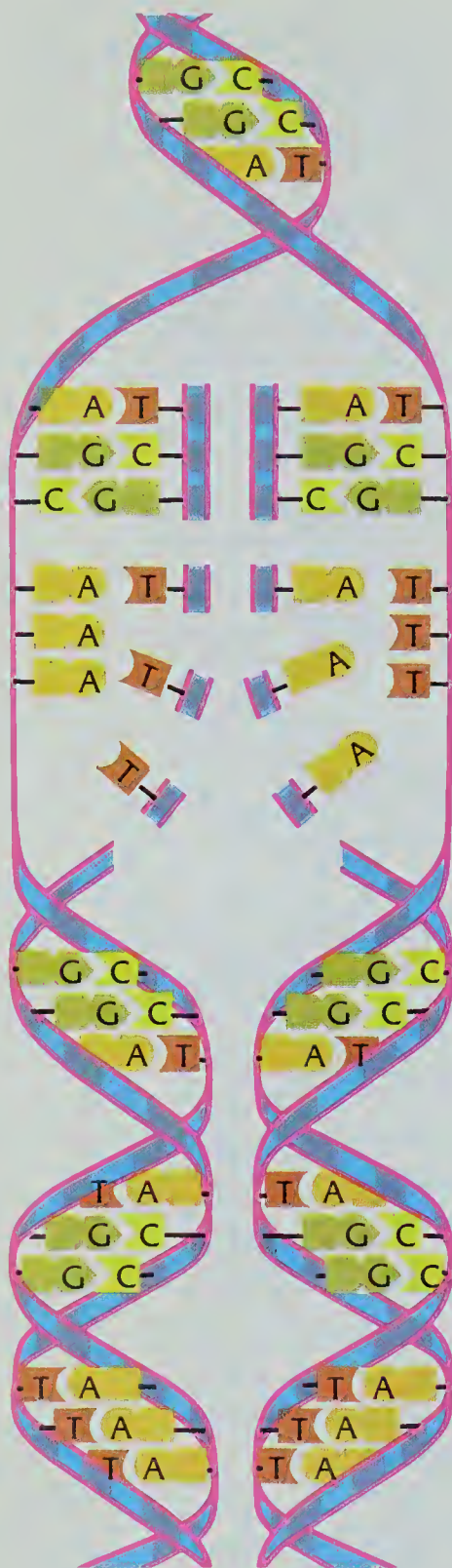


FIGURE 4-4

As a result of the base-pairing rule, DNA replication produces two new molecules identical to the original one.

Because of the base-pairing rule, both of the “unzipped” halves of the DNA molecule will end up with the same kind of nucleotides as were in the original molecule. Thus two identical DNA molecules result, and the process of replication is complete.

CHECK YOUR FACTS

1. Who first proposed the model for DNA structure that is now widely accepted?
2. How many DNA molecules might one expect to find in a prokaryotic cell?
3. Name two types of eukaryotic DNA. Where are they found?
4. Three chemical groups make up each nucleotide. Name them.
5. Name the nitrogen bases found in DNA.
6. Cytosine is bonded to the nitrogen base of another nucleotide. What type of chemical bond is present? What is the other nucleotide?
7. What is DNA replication?
8. Where would the “old” DNA molecule be found after it has replicated?
9. Which nucleotide bases will not bond to guanine?

Translating the Genetic Code

4-6 The genetic code DNA molecules contain all the instructions necessary for a cell to build thousands of different proteins. Those instructions are in a special kind of code called the **genetic** (jə net'ik) **code**. The genetic code is a sequence of nucleotides in DNA that specifies the sequence of amino acids that go into proteins. It is called a genetic code because the information is inherited whenever an organism reproduces. The information in the genetic code is also called genetic information. In eukaryotic cells the genetic information is in the nucleus. However, in these same cells proteins are synthesized in the cytoplasm. Somehow the code in the DNA has to be “read,” or translated, and then carried out into the cytoplasm. For example, the code in the nucleus might say: Put the amino acid lysine in the first position in a polypeptide chain. But the actual process of assembling a polypeptide with lysine in the number one position is done outside the nucleus, in the cytoplasm. How does this information get from the nucleus to the cytoplasm?

4-7 Messenger RNA There is another molecule in the cell that serves as a messenger for carrying genetic information from the nucleus to the cytoplasm. That molecule is called **messenger RNA (mRNA)**.

The correct name for **RNA** is **ribonucleic** (rī bō nū klē'ik) **acid**. It too is a long molecule made up of nucleotides. However, it differs from DNA in three ways. First, it is a single helix rather than a double helix. (Picture it as half of a DNA molecule after it has “unzipped.”) Second, the sugar in the nucleotides is ribose rather than deoxyribose. Third, it has a different nitrogen base in one of its four nucleotides. This is called **uracil** (yūr'ə səl). Uracil replaces thymine, which is not found in RNA.

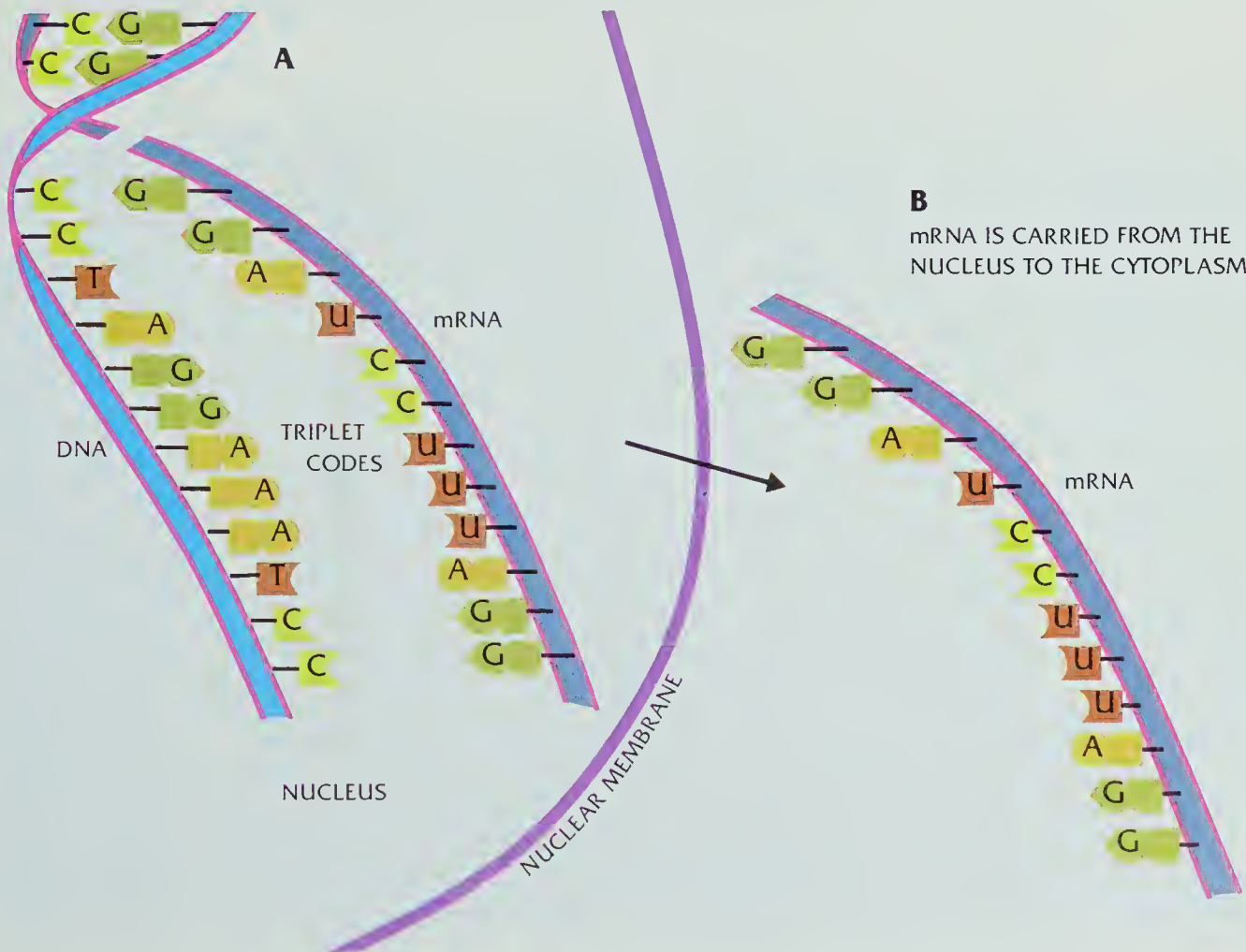
4-8 Reading the code For the code in DNA to be “read,” or translated, the DNA must “unzip.” This exposes a sequence of nitrogen bases to which RNA bases become linked. The code itself is a triplet code. This means that a sequence of three bases, called a **codon** (kō'don), is needed to specify one amino acid. For example, suppose

ANSWERS TO CHECK YOUR FACTS

1. James Watson and Francis Crick.
2. One.
3. Nuclear DNA is found in the nucleus. Organelle DNA is found in organelles.
4. A phosphate group, a deoxyribose sugar, a nitrogen base.
5. Thymine, adenine, guanine, and cytosine.
6. Hydrogen bond. Guanine.
7. The process by which a DNA molecule reproduces.
8. Each of the two “new” molecules would contain half of the “old” DNA molecule.
9. Adenine, thymine, guanine

FIGURE 4-5

Each messenger RNA molecule is formed by base-pairing with an unzipped section of DNA.



SCIENCE TERMS

genetic code
messenger RNA
ribonucleic acid
uracil
codon

MAIN IDEA (4–8)

The genetic code is read when a portion of a DNA molecule “unzips” and messenger-RNA bases form on the exposed DNA nucleotides. Later the mRNA peels off and moves to the cytoplasm, carrying triplet sequences, called codons, that correspond to the code in DNA.

SCIENCE BACKGROUND

Recent work has shown that neither strand of DNA is exclusively translated.

the following sequence of nitrogen bases were exposed on a DNA molecule:

DNA CAATTCCGAGGG

RNA nucleotides would combine with the exposed DNA bases as follows:

DNA CAATTCCGAGGG

mRNA GUUAAGGCUCCC

We can now see what information the mRNA has taken from the DNA. The first step is to break down the mRNA sequence into codons:

mRNA GUU AAG GCU CCC

By using Table 4–1, we can translate the mRNA code into the different amino acids. Codon GUU specifies the amino acid valine. Codon AAG specifies lysine. GCU specifies alanine, and CCC specifies proline.

After the mRNA is completely formed on the exposed DNA bases, it separates, or “peels off,” and moves out into the cytoplasm. Thus the mRNA in our example carries the following message to the protein synthesis machinery in the cytoplasm: Build a polypeptide with the valine–lysine–alanine–proline sequence of amino acids.

Table 4–1 The Genetic Code in mRNA

<i>First Position</i>	<i>Second Position</i>				<i>Third Position</i>
	U	C	A	G	
U	Phenylalanine	Serine	Tyrosine	Cysteine	U
	Phenylalanine	Serine	Tyrosine	Cysteine	C
	Leucine	Serine			A
	Leucine	Serine		Tryptophan	G
C	Leucine	Proline	Histidine	Arginine	U
	Leucine	Proline	Histidine	Arginine	C
	Leucine	Proline	Glutamine	Arginine	A
	Leucine	Proline	Glutamine	Arginine	G
A	Isoleucine	Threonine	Asparagine	Serine	U
	Isoleucine	Threonine	Asparagine	Serine	C
	Isoleucine	Threonine	Lysine	Arginine	A
	Methionine	Threonine	Lysine	Arginine	G
G	Valine	Alanine	Aspartic Acid	Glycine	U
	Valine	Alanine	Aspartic Acid	Glycine	C
	Valine	Alanine	Glutamic Acid	Glycine	A
	Valine	Alanine	Glutamic Acid	Glycine	G

CHECK YOUR FACTS

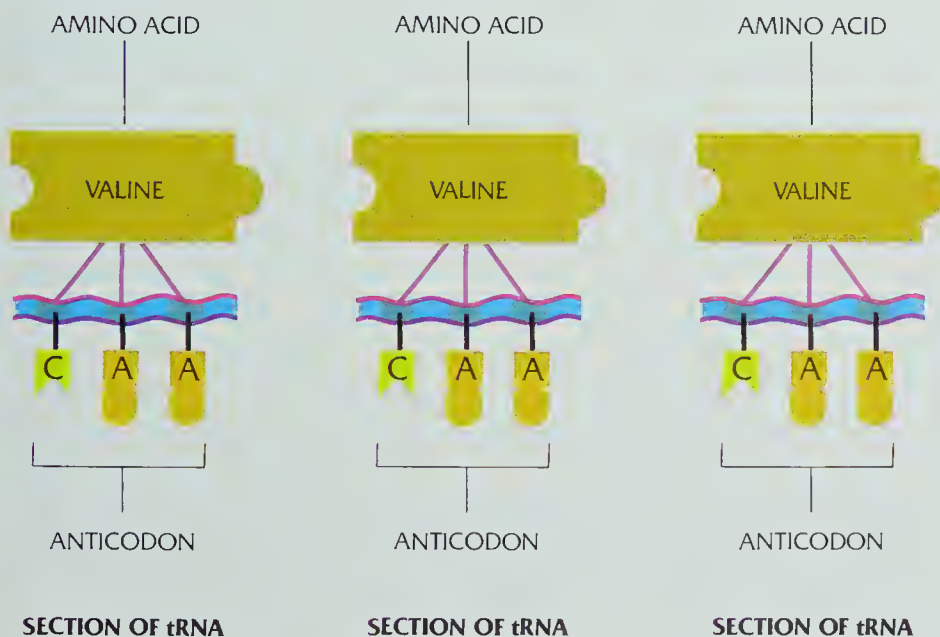
1. What is the role of DNA in protein synthesis?
2. What function does mRNA serve?
3. Name three ways RNA differs in structure from DNA.
4. A DNA strand reads GTCCGATTC. What mRNA strand would be produced? What amino acids are encoded here?
5. What is a codon?

Protein Synthesis

4-9 More RNA In the cytoplasm of the cell, where amino acids are assembled into polypeptides and proteins, there are two more types of RNA. One type called **ribosomal RNA (rRNA)** is found in the ribosome. The other type called **transfer RNA (tRNA)** is scattered about the cytoplasm. The tRNA molecules are much smaller than the other two types. The first tRNA molecule analyzed in the laboratory was found to have only 77 nucleotides.

4-10 The role of transfer RNA The tRNA has a very important role in protein synthesis. It is the tRNA molecules that combine with the different amino acids. There is one specific type of tRNA for each of the 20 different amino acids. Also, each tRNA has three exposed nucleotides called an **anticodon** (an tē kō'don). An anticodon

FIGURE 4-6 Each type of transfer RNA combines with only one type of amino acid.



ANSWERS TO CHECK YOUR FACTS

1. DNA contains the information that specifies the primary structure of the protein.
2. It carries the coded instructions from the DNA in the nucleus to the site of protein synthesis in the cytoplasm.
3. (a) It is a single helix. (b) It has ribose, not deoxyribose. (c) Uracil is present in place of thymine.
4. CAGGCUAAG. Glutamine—alanine—lysine.
5. A sequence of three bases that code for one amino acid.

MAIN IDEA (4-9)

Two other types of RNA are found in the cytoplasm. Both help in the building of polypeptides. Ribosomal RNA is in the ribosomes. Transfer RNA, a much smaller form, is scattered about the cytoplasm.

MAIN IDEA (4-10)

Twenty different kinds of transfer RNA attach to the different amino acids and carry an exposed three-nucleotide sequence, called an anticodon, that will combine with a codon of mRNA.

SCIENCE BACKGROUND

The rate of chain growth in protein synthesis is up to 40 amino acids per second in *E. coli*, with estimates ranging up to 600 amino acids per minute in eucaryotic cells. Many antibiotics are effective against bacterial cells by interfering with protein synthesis in some way.

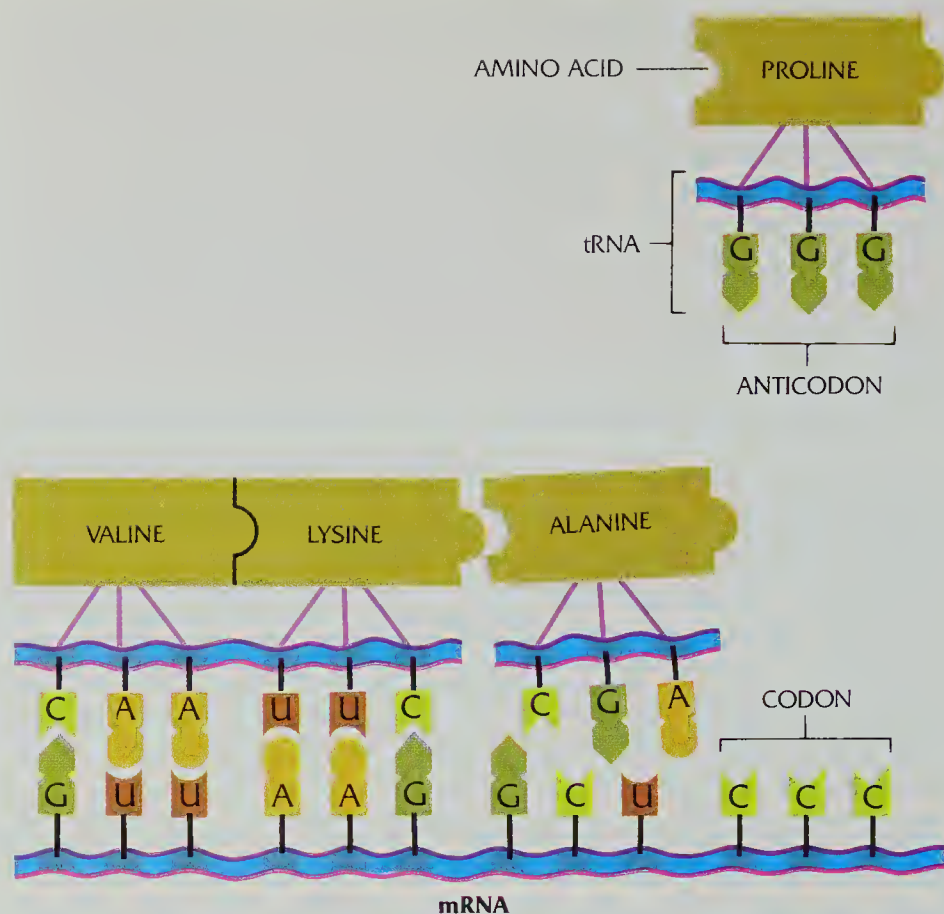


FIGURE 4-7 The pairing of codons and anticodons results in the correct sequence of amino acids in the polypeptide chain.

SCIENCE TERMS

ribosomal RNA

transfer RNA

anticodon

polysome

MAIN IDEA

The ribosome, made up of half rRNA and half protein, acts as a sort of "workbench" for the assembly of amino acids.

MAIN IDEA

The polypeptide is assembled when tRNA's having different amino acids and specific anticodons unite with the codons of mRNA, with the assistance of ribosomes. The correct amino acids are properly lined up by this procedure, and they are linked into a polypeptide by a series of dehydration synthesis reactions.

contains a sequence of three nitrogen bases that will combine with a codon.

4-11 The ribosomes About 50 percent of each ribosome is made up of rRNA. The other 50 percent is protein. It is not known how the ribosome functions during protein synthesis. However, it is known that ribosomes provide a sort of moving "workbench" where the amino acids are assembled. During the actual assembly process several ribosomes may be clustered together into what is called a **polysome** (pol'ē sōm).

4-12 Making the polypeptide The machinery that actually assembles the polypeptide consists of three major parts: (1) mRNA with its codons; (2) 20 different tRNA's with their amino acids and anticodons; and (3) ribosomes.

Now we will see how they function together. As an example, we will use the mRNA with the codons for the four amino acids discussed earlier: valine—lysine—alanine—proline.

The basic stages in making the polypeptide are summarized below.

1. The mRNA with its codons moves from the nucleus to the cytoplasm.

2. The tRNA's in the cytoplasm become chemically bonded to the 20 different amino acids.

3. The ribosomes get involved in attaching the correct tRNA anticodon to the mRNA codons. For example, valine tRNA has the anticodon CAA which combines with the mRNA first codon, GUU. Then the ribosomes help link the lysine tRNA anticodon to the mRNA second codon, AAG. See Figure 4–7. In the same manner the other tRNA's are linked to the messenger.

4. When the tRNA's become linked to the mRNA the amino acids are lined up in the sequence specified by the DNA genetic code. Then, through a series of dehydration syntheses, the adjoining amino acids form peptide bonds. Also the amino acids are released from their tRNA carriers, thus freeing the polypeptide chain.

5. Next, the polypeptide chains coil, twist, and fold and may become linked with other chains. The net result is a protein built to the exact specifications of the DNA code.

4–13 Organelle DNA Mitochondria and plastids, such as chloroplasts, also contain DNA with genetic information. It is known that organelle DNA can replicate itself. It is also known that those organelles contain RNA and other chemicals needed for protein synthesis. However, it has not yet been learned how the protein synthesis occurs. It may or may not occur in the same way that genetic information in nuclear DNA is used to make polypeptides in the cytoplasm.

CHECK YOUR FACTS

1. Where is tRNA found? What is its function?
2. What is an anticodon?
3. An anticodon reads UCA. To what amino acid is this anticodon bonded?
4. What is a polysome? What activity occurs there?
5. What machinery is involved in the assembling of polypeptides?
6. What type of chemical reaction links the amino acids into polypeptides?
7. What is known and not known about organelle DNA and protein synthesis?

SCIENCE BACKGROUND

The proteins synthesized from DNA in the mitochondrion are subunits of proteins that function in the catabolic (breakdown) reactions that occur in this organelle. However, it is estimated that no more than 5 to 10 percent of the proteins in mitochondria are coded in this organelle's DNA. Most components of the proteins are synthesized from nuclear DNA and transported to the organelle. Studies of chloroplasts and their DNA suggest a similar pattern.

MAIN IDEA

It is known that organelle DNA can replicate itself and that the components needed for protein synthesis are present. The exact method of protein synthesis is not yet understood.

ANSWERS TO CHECK YOUR FACTS

1. In the cytoplasm. It selectively bonds with mRNA and the amino acid coded for, thus completing transfer of the code.
2. A sequence of three nucleotide bases found on tRNA that will combine with a codon.
3. Threonine.
4. A cluster of ribosomes. It is the site of protein synthesis.
5. mRNA with codons, 20 tRNA's with amino acids, and ribosomes.
6. Dehydration synthesis.
7. It is known that it can replicate itself and that other protein synthesis materials are in the organelles. It is not known how protein synthesis occurs in organelles.

Genes and Mutations

MAIN IDEA

A gene is a sequence of nucleotides in a DNA molecule that specifies the amino acid sequence of one polypeptide.

SCIENCE BACKGROUND

An exception to the text definition of a gene is the gene of RNA viruses—it is a sequence of RNA nucleotides that codes for an amino acid sequence of one polypeptide.

MAIN IDEA

Mutations, which are changes in genes, can result from various errors and changes in the DNA molecule.

SCIENCE BACKGROUND

Spontaneous mutations occur about once in each million gene replications. One explanation for spontaneous mutations is that the bases tend to spend a small amount of time in alternate tautomeric forms, which would allow such a form of thymine, for example, to bond to guanine instead of adenine.

4–14 Defining the gene For many years biologists have known that characteristics of organisms are inherited by units in the chromosomes called **genes** (jēnz). Now, with our present knowledge of DNA and protein synthesis, the gene can be given a precise definition. A gene is defined as the sequence of nucleotides in a DNA molecule that specifies the amino acid sequence for one polypeptide chain.

If it is known how many polypeptide chains are in a protein, we will also know how many genes carry information for that protein. A protein with four polypeptide chains will require information from four genes. Also, if the number of amino acids in a polypeptide is known, we will know how many nucleotides must be in the gene. A polypeptide chain with 300 amino acids would have a gene with 900 nucleotides.

4–15 Mutations Any permanent change in one or more genes of an organism that can be inherited is called a **mutation** (myü tā'shən). Many years ago mutations were produced in the laboratory by exposing fruit flies to heavy doses of X-ray radiation. Later, mutations were produced by exposing organisms to other types of radiation and to a variety of chemicals called **mutagens** (myü'tə jənz). In these early experiments it was known that the genes were changed, but the exact nature of the changes was unknown.

Researchers are beginning to understand exactly how some mutations occur. For example, some mutagens cause changes in the nitrogen bases, so that when the DNA molecule replicates, different nitrogen bases become paired. An example is a mutagen called bromouracil, which replaces thymine in DNA. When the DNA with the bromouracil replicates, the bromouracil pairs with guanine instead of adenine. The next time the DNA replicates, one molecule would have a guanine-cytosine pair of nucleotides rather than an adenine-thymine pair. In turn, this would change the codon, and the change could result in a different amino acid being placed in a polypeptide.

Mutation such as that described above does not always result in a different polypeptide. This is because the genetic code is redundant, which means that there is more than one codon in the genetic code for each amino acid. It is possible that a shift from an AT to a GC sequence could result in another codon that would also specify the same amino acid.

4-16 Genes, mutations, and cancer Cancer is an often deadly disease that results when certain cells lose their ability to control themselves. This lack of control causes them to reproduce rapidly and can be the cause of a malignant tumor. Many things are known to cause cancer in experimental animals. Among them are the same things that cause mutations, such as various types of radiation and chemical mutagens. This discovery was not surprising to biologists.

All functions in the cell are controlled by **enzymes** (en'zīnz), which are large proteins. Radiation or a mutagen that changes a gene can also result in a structural change in an enzyme. You learned in Chapter 3 that the substitution of one different amino acid in two chains of the hemoglobin molecule was enough to change the hemoglobin's ability to function. Cancer researchers also think that someday the precise cause of some kinds of cancer may be traced to specific kinds of mutations.

4-17 Genetic engineering The term **genetic engineering** is used to describe the attempts by scientists to make precise changes in the genes of organisms. This is a controversial subject that you will hear debated in the years ahead.

One very controversial kind of genetic engineering is called a **recombinant** (ri kom'bə nənt) **DNA** experiment. An example is the recombinant DNA experiment to

MAIN IDEA

Cancer researchers think the cause of some kinds of cancer may be traceable to specific mutations in DNA.

SCIENCE TERMS

genes
mutation
mutagens
genetic engineering
recombinant DNA

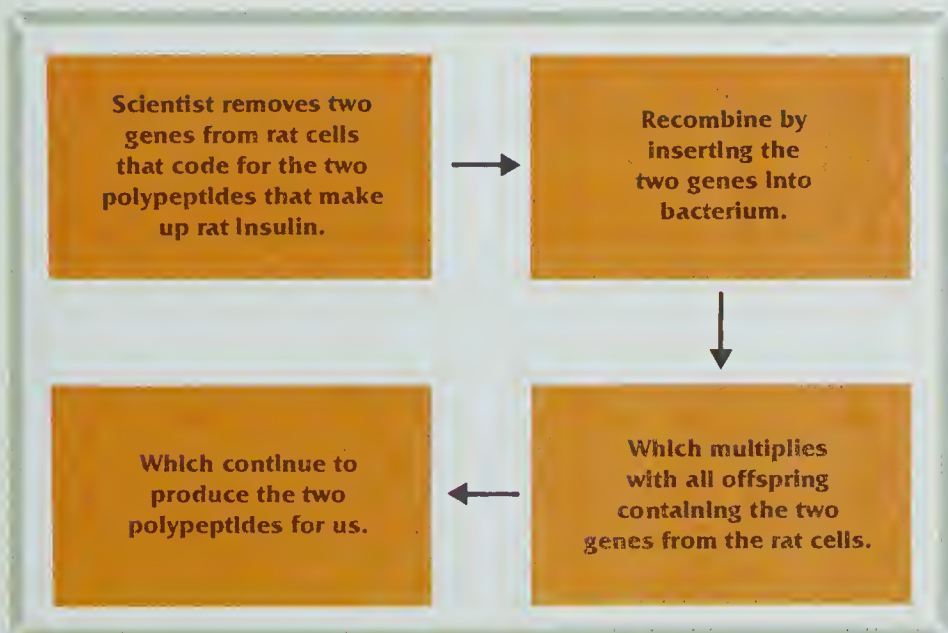
MAIN IDEA

Genetic engineering is the term used to describe efforts of scientists to change genes in organisms. Genetic engineering is very controversial, and the experiments with recombinant DNA are typical of those causing controversy, even among scientists.

SCIENCE BACKGROUND

One new problem that may slow down development of recombinant DNA is the discovery that the arrangement of genes in eucaryotic cells is probably different from that in procaryotic cells. Specifically it has been discovered that there are large nucleotide sections called spacer sequences that are not present in the messenger that transcribes the gene.

FIGURE 4-8 In recombinant DNA experiments, genes from one organism are combined with the DNA of another organism.



ANSWERS TO CHECK YOUR FACTS

1. The sequence of nucleotides in a DNA molecule that specifies the amino acid sequence for one polypeptide chain.
2. Five genes.
3. 222.
4. A chemical that can cause a mutation to occur. Bromouracil. It replaces thymine in DNA but bonds with guanine instead of adenine when DNA replicates.
5. If a change in the DNA does not produce a different amino acid sequence, the gene will function normally, despite the mutation.
6. If the proper controlling enzymes are not made, unregulated reproduction could result. A mutation could cause such a loss of the needed enzymes.
7. It describes the efforts to make precise mutations in genes with resulting beneficial changes in gene functions. It is controversial because the results obtained are not always predictable and could even be dangerous.

ANSWERS TO REVIEW QUESTIONS

1. DNA contains the genes that code for the amino acid sequence, or primary structure, of proteins. The cell is regulated by the proteins.
2. (a) mRNA: Carries codons from DNA to cytoplasm. (b) tRNA: Carries amino acids to mRNA where polypeptide is assembled. (c) rRNA: Helps in

produce insulin. Insulin is a protein. In a disease called diabetes the body cannot manufacture enough insulin. Persons with diabetes, called diabetics, must often use insulin that has been processed from cows and pigs. This insulin, which has a slightly different primary structure from that of human insulin, sometimes causes allergic reactions.

Biologists are doing recombinant DNA experiments in an attempt to find a way to produce pure human insulin. So far, they have removed from rat cells the two genes that code for the two polypeptide chains in rat insulin. They recombined those genes in the DNA of bacteria called *E. coli*. The new DNA in the bacteria with the rat genes, called recombinant DNA, causes the bacteria to produce rat proinsulin. Rat proinsulin is a protein that needs to be modified only slightly to be converted to rat insulin. The next step is to isolate the two genes that code for human insulin and recombine them with *E. coli*.

What is controversial about the recombinant DNA experiments? One major objection to such experiments is that very dangerous organisms, such as disease-producing bacteria, might accidentally be created. Suppose, for example, a recombinant DNA experiment produced a bacterium that was immune to all kinds of antibiotics. And suppose that bacterium escaped, causing a deadly disease in people or in other organisms. What could be used to kill such bacteria? Would the disease wipe out millions of people or other organisms? Such a threat, though improbable, deeply concerns many scientists. It is one reason why some scientists are strongly opposed to recombinant DNA experiments, even though they might also prove helpful to people. The insulin experiments are an example of how genetic engineering can be helpful.

CHECK YOUR FACTS

1. What is a gene?
2. How many genes would be needed for a protein made up of five polypeptide chains?
3. A polypeptide made up of 74 amino acids would be made from a gene with how many nucleotides?
4. What is a mutagen? Give an example and explain how it functions.
5. Why might a mutation be harmless?
6. Explain why cancer might be linked to specific kinds of mutations.
7. What is meant by the term *genetic engineering*? Why is this field so controversial?

SUMMARY

DNA contains the information needed to manufacture the thousands of different proteins required by an organism. Although some DNA exists in organelles, most DNA is in the nucleus of the cell. The Watson-Crick model of DNA provides the currently accepted explanation of replication and protein synthesis. In replication the double-stranded molecule “unzips,” and nucleotides from the cell environment attach to the exposed strands. The base-pairing rule assures that exact duplicates are made. In protein synthesis a strand of mRNA is formed on an exposed section of DNA. A gene is a sequence of nucleotides in a DNA molecule that specifies the amino acid sequence for one polypeptide chain. Most proteins have several polypeptide chains; hence several genes are necessary to produce one protein.

REVIEW QUESTIONS

1. What is the function of DNA in the cell?
2. What are the three kinds of RNA and what are their functions?
3. What is meant when we say the genetic code is redundant? Why might this be important when considering a mutated gene?
4. List three differences between DNA and RNA.
5. An “unzipped” DNA strand exposes the following nucleotides: ATGGCATTGAGG. What mRNA sequence will form? What amino acid sequence will result?
6. If the DNA described above is changed so that the last nucleotide is replaced by adenine, how will the amino acid sequence be affected? What if the last nucleotide were guanine or thymine?

ANALYSIS AND APPLICATION

1. Can you suggest a reason why researchers first suspected that a codon consists of three nucleotides and not two?
2. If genetic engineers perfect the production of human pro-insulin by bacteria, what benefits can we expect?
3. Your body started from one cell. All your present cells contain DNA that is identical to that contained in the first cell. How can you account for the wide variety of cell types in your body if they all have identical “codebooks”?
4. Some cells can live for a while after the nucleus is removed. But they gradually lose some of their abilities and eventually die. In terms of DNA and protein synthesis, how might that be explained?

assembling amino acids into polypeptides.

3. There is more than one codon for each amino acid. This redundancy could allow a mutated gene to function normally.

4. (a) DNA is a double helix, not a single helix. (b) DNA has deoxyribose, not ribose. (c) DNA has thymine nucleotides instead of uracil nucleotides.

5. UACCGUUUCUCC.

Tyrosine—arginine—
asparagine—Serine.

6. If adenine is the new nucleotide, no change will occur. If the new nucleotide is guanine or thymine, phenylalanine will replace leucine in the polypeptide chain.

ANSWERS TO ANALYSIS AND APPLICATION

1. There are only 16 possible combinations when only two bases are used. Since there are more than 16 amino acids, a more versatile code is needed.
2. Allergic reactions to the insulin would not occur. The eventual cost of insulin would probably drop below the present cost.
3. Different genes are translated in different cells to cause the differences.
4. Such a cell “gets by” for a while on the information already transferred to the cytoplasm by mRNA, but with no new information coming, the cell cannot build the proteins it needs and thus loses vital functions and eventually dies.

Investigations 10–14 from *Laboratory Investigations in Biology*
can be done with this chapter

5 *Energy in*



OBJECTIVES

- To understand that all energy in organisms comes from the energy in chemical bonds
- To appreciate the importance of enzymes in catalyzing reactions
- To understand the role of ATP as the universal energy currency in all cells
- To name examples of producers and consumers and explain the difference between them
- To understand the structure of a chloroplast and how chlorophyll functions in transforming light into ATP and NADPH
- To explain the difference between the light reactions and dark reactions of photosynthesis
- To understand that sugar is just one of many products of photosynthesis
- To understand cellular respiration and how it differs from the breathing process

the Cell

Metabolism, enzymes, and ATP

5–1 Work and energy All organisms perform various kinds of work. However, the work is actually done *inside* the cells. For example, muscle cells produce movement and nerve cells transmit information. Many different kinds of cells manufacture products such as proteins and carbohydrates.

Energy (en'ər jē) is defined as the ability to do work. Therefore, cells must have energy to perform their work. Where do they get their energy?

5–2 Chemical-bond energy All cells use a special kind of energy called **chemical-bond energy**. This is energy that is released when the chemical bonds of a molecule are broken. To observe an example of chemical-bond energy, heat some kind of food, such as a peanut. The heat will start a chemical reaction between the peanut and oxygen from the air. In this reaction the molecules in the peanut start to break down. They recombine with oxygen. Once the reaction has started, an outside source of heat is no longer needed to keep the reaction going. The heat released when the bonds are broken keeps the reaction going. Light energy is also released. This energy is visible in the flame.

Heat can cause a chemical reaction to occur because it increases the movement of molecules. Greater movement does two things. First, it increases the chances that molecules will collide with each other. Molecular collisions are necessary for reactions to occur. Second, heat increases the

MAIN IDEA

Cells need energy to perform their necessary work.

MAIN IDEA

All cells use the energy that is released when bonds are broken during chemical reactions.

SCIENCE BACKGROUND

To introduce this chapter, it is recommended that a peanut be burned for the class, or that the students be allowed to burn it. One procedure is to push a pin in a cork, head first, then stick the peanut on the point of the pin. It is easier to light the peanut with a wooden match because it burns longer; sometimes it takes considerable heating to start the peanut burning.

strength of molecular collisions. The stronger the molecular collisions, the greater the chance that a reaction will occur. When a lighted match is held up to a peanut, the heat increases both the number and strength of the molecular collisions until the chemical reaction occurs.

MAIN IDEA

The chemical reactions in organisms—called metabolism—are controlled by enzymes, which are catalysts.

SCIENCE BACKGROUND

There are two other characteristics of enzymes. They are needed in extremely small quantities because each one can catalyze thousands of reactions. Too, enzymes work very efficiently, catalyzing thousands of reactions per second.

MAIN IDEA

Enzymes are protein molecules, sometimes with nonprotein coenzymes, that have active sites that attract specific molecules (the substrates). The substrates react with each other without affecting the enzymes themselves.

SCIENCE BACKGROUND

Coenzymes that are not vitamins usually have vitamins that make up part of their structure. The coenzymes often function as acceptor or carrier molecules for molecules that enter the reactions. Nucleotides also may be components of coenzymes.

FIGURE 5-1

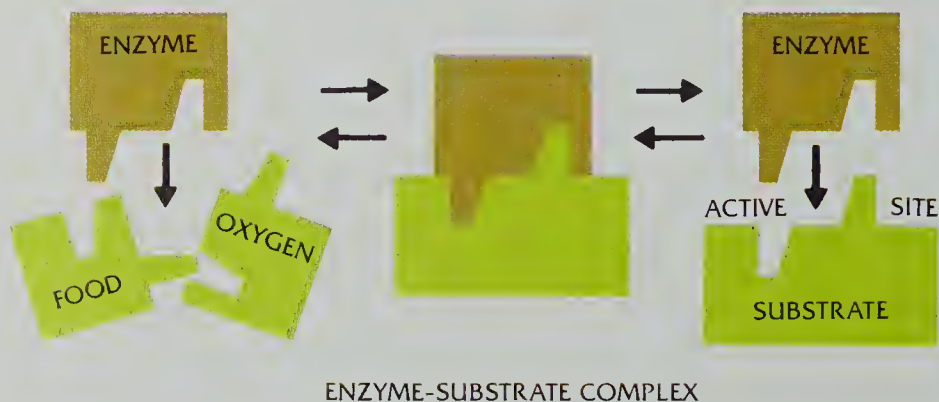
Enzymes are able to catalyze chemical reactions by the formation of an enzyme-substrate complex.

5-3 Reactions without applying heat The total of all chemical reactions that occur in cells is called **metabolism** (mə tab'ə liz əm). Such reactions, called metabolic reactions, require energy. However, the cell cannot use as much energy as we use to start a peanut burning. Nor can the cell allow reactions to release as much energy as is released when a peanut burns. Both the heat used to start the reactions and the heat released during the reactions would destroy the cell. How, then, are metabolic reactions started and controlled?

Most metabolic reactions in the cell are started and controlled by a group of chemicals called **enzymes**. Enzymes act as **catalysts** (kat'ə lists). Catalysts are chemicals that cause chemical reactions to occur without themselves being changed during the reactions. As catalysts, enzymes start chemical reactions and keep them going without the addition of large amounts of heat energy.

5-4 How enzymes function All enzymes are protein molecules. Some enzymes also have nonprotein subunits called **coenzymes** (kō en'zīmz) that unite with them and help them function. Some of the coenzymes are vitamins, such as riboflavin and niacin.

Enzymes function by forming temporary chemical bonds with the molecule or molecules that are to undergo a chemical reaction. Such a molecule or molecules are called the **substrate** (sub'strāt). The region of the enzyme where the substrate bonds is called the **active site** (sīt). Picture the substrate as being like one or two pieces of a jigsaw puzzle that fit into one hole, which is the active site.





Chemical reactions in the body can supply energy for work and exercise. Such reactions also release metabolic heat.

When two molecules of a substrate are bonded to an active site, there is no longer a random chance that they will collide. They have to collide because the enzyme is holding them close together. The reaction may unite two molecules, or it may separate one molecule into two. In many cases both reactions are occurring, and the reaction that occurs most often, or the net reaction, is what is observed.

Biologists are not sure exactly how reactions occur at the enzyme active site. However, they do know that after the reactions occur, the substrate is released from the active site. This leaves the active site vacant and allows the enzyme to react with another substrate. Working this way, one enzyme can catalyze many reactions without itself being changed.

5-5 Why doesn't metabolism burn up cells?

The work of enzymes explains how reactions can be started without adding heat that would burn up the cell. But what about the heat that is released during metabolism? How can metabolic reactions occur without excess heat from the reactions burning up the cell?

The cell does not burn up when reactions occur for two reasons. First, the reactions do not occur all at once, as they do in a peanut that is burning. Teams of enzymes cause reactions to occur in a series of steps, with small amounts of energy released during each step. Second, only part of the energy released during metabolism is converted to heat. (Feel the warmth of your body. This is metabolic heat that keeps your body temperature at 37°C .) Much of the energy is used to convert ADP to ATP.

MAIN IDEA

The heat of metabolism does not burn up cells because the energy of the reactions is released in a series of small steps and only a part of the energy is released as heat.

MAIN IDEA

Most energy of chemical reactions is stored in the high energy bond that links a phosphate group to ADP and forms ATP.

SCIENCE BACKGROUND

It might be interesting to point out that adenosine monophosphate (AMP) is one of the DNA nucleotides.

Technically not all the energy from the hydrolyzation of the third phosphate from ATP comes from the bond. Part of the energy results from the unique configuration in the internal structure of the molecules.

5–6 What are ADP and ATP? Adenosine diphosphate, or ADP, is an RNA nucleotide with one extra phosphate group. **Adenosine triphosphate, or ATP,** also is an RNA nucleotide, but it has two extra phosphate groups.

Note in Figure 5–2 the wavy lines that link the last phosphate to ADP and the last two phosphates to ATP. Those wavy lines are symbols for a special high-energy covalent bond. The breaking of such bonds results in the release of more energy than the breaking of covalent bonds in other compounds.

ADP, ATP, and individual phosphate groups are found throughout the cell and are involved in most metabolic reactions. When energy is released during a metabolic reaction, some of the energy is used to link a phosphate group to ADP, forming ATP. This is called **phosphorylation** (fos fər ə lā'shən). Later, when energy is needed in the cell, the high-energy bond linking the third phosphate to ATP is broken. This releases energy that can do work, and a molecule of ADP is left. Thus there is an ADP–ATP cycle in the cell. When energy is released, it is used to make ATP from ADP. When energy is needed, it is released from ATP and ADP is formed.

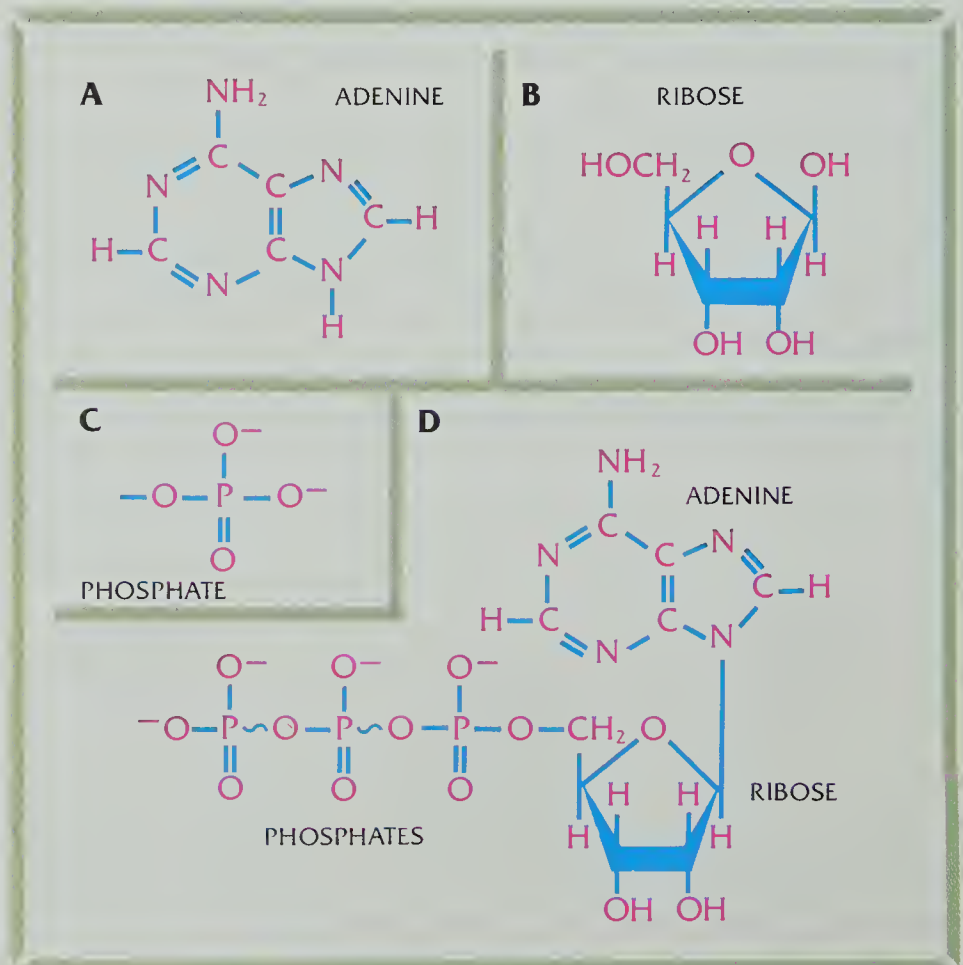


FIGURE 5–2

The structure of ATP is shown in this figure.

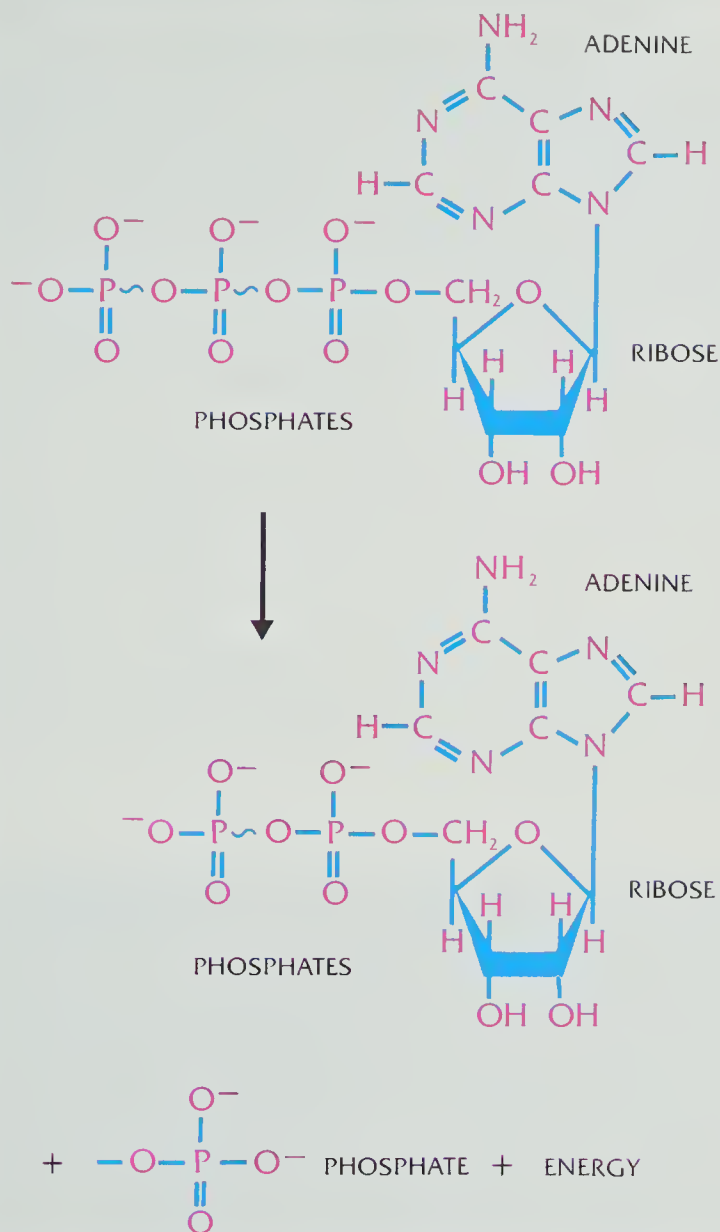


FIGURE 5-3

The breakdown of ATP yields ADP plus phosphate and energy.

SCIENCE TERMS

energy
chemical bond energy
metabolism
enzymes
catalysts
coenzymes
substrate
active site
adenosine diphosphate (ADP)
adenosine triphosphate (ATP)
phosphorylation

ANSWERS TO CHECK YOUR FACTS

1. The ability or capacity to do work.
2. Chemical bond energy.
3. It causes the molecules to speed up. This increases the frequency and force of molecular collisions.
4. The sum total of all chemical reactions that occur in cells.
5. Enzymes.
6. Because they cause chemical reactions to occur without themselves being changed.
7. The region of the enzyme where the substrate bonds.
8. ATP has an additional phosphate group attached and therefore has more energy stored in its chemical bonds.

CHECK YOUR FACTS

1. What is energy?
2. What kind of energy is used by cells?
3. Why does heat help cause a reaction?
4. What does *metabolism* mean?
5. What controls metabolic reactions?
6. Why are enzymes called catalysts?
7. What is meant by *active site*?
8. How are ADP and ATP different?

Photosynthesis

MAIN IDEA

Producers are organisms that carry on photosynthesis and transform energy from the sun into food and other important molecules. Consumers are organisms that feed upon producers. All organisms—producers and consumers—ultimately depend upon the sun for their energy.

SCIENCE BACKGROUND

There are a few exceptions to the rule that all organisms directly or indirectly depend upon the sun for their energy. Some microbes have the ability to transform energy and synthesize foodstuffs by using the chemical bond energy of inorganic compounds.

5–7 *Where does energy for life come from?*

With the exception of a few rare types of microorganisms, the earth's organisms obtain their energy directly or indirectly from the sun. The radiant energy of sunlight is transformed into chemical-bond energy by the process of **photosynthesis** (fō tə sin'thə sis). The photosynthetic organisms, which include green plants and several kinds of microorganisms, are called **producers**. The producers transform radiant energy into chemical-bond energy, which is then used to manufacture many different molecules, including sugars, fats, amino acids, and nucleotides.

Other organisms, which cannot carry on photosynthesis, are called **consumers** (kən sü'märz). All animals are consumers, as are many microorganisms. The consumers obtain their energy from the chemical bonds of food molecules that they have eaten. The energy in the food molecules came directly from producers, or from animals that had eaten producers. Therefore all consumers, directly or indirectly, depend upon producers for their energy. Thus the energy that organisms use for all their work comes from the sun.



Animals, such as this water buffalo, are consumers. All consumers depend on energy trapped by plants in photosynthesis.

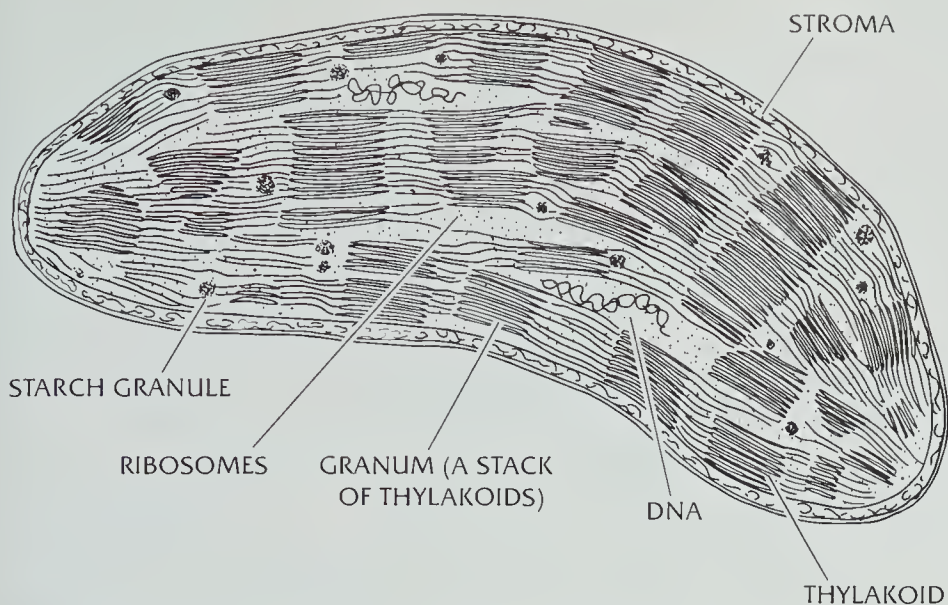


FIGURE 5-4 The structure of a chloroplast is shown in this figure.

5-8 Where does photosynthesis occur? In almost all producers photosynthesis occurs inside cellular organelles called **chloroplasts**. (The exception is in prokaryotic cells of organisms such as blue-green algae.) Under the light microscope a chloroplast looks like a small round green object floating in the cytoplasm. But with the electron microscope a more detailed structure is revealed. Scattered throughout the chloroplast are small bodies called **grana**, which are made up of stacks of disklike plates. The disklike plates are called **thylakoids** (thī'lə koids). The region outside the grana, called the **stroma** (strō'mə), has no definite structure and is somewhat like the cytoplasm of the cell.

5-9 The pigments The first stage of photosynthesis is the capture of radiant energy. This is done by **pigments**, which are chemicals that absorb certain colors in the visible light spectrum.

A green pigment found in the chloroplast is called **chlorophyll**. It absorbs red and blue colors of the visible light spectrum and radiates the color green. That is why it appears green to us. Actually there are two kinds of chlorophyll in the chloroplasts of most organisms. One, called **chlorophyll a**, is the most universal, which means that it is found in the greatest number of organisms. The other, called **chlorophyll b**, is also common. Chlorophyll *b* supplements the light absorption ability of chlorophyll *a* by absorbing colors that are not absorbed by chlorophyll *a*.

SCIENCE BACKGROUND

Some of the thylakoids have membrane extensions that connect them with the other grana. Some chloroplasts, as in red algae, lack grana and have stromal lamellae. The leaves of higher plants contain hundreds of thousands of chloroplasts per square millimeter of leaf surface.

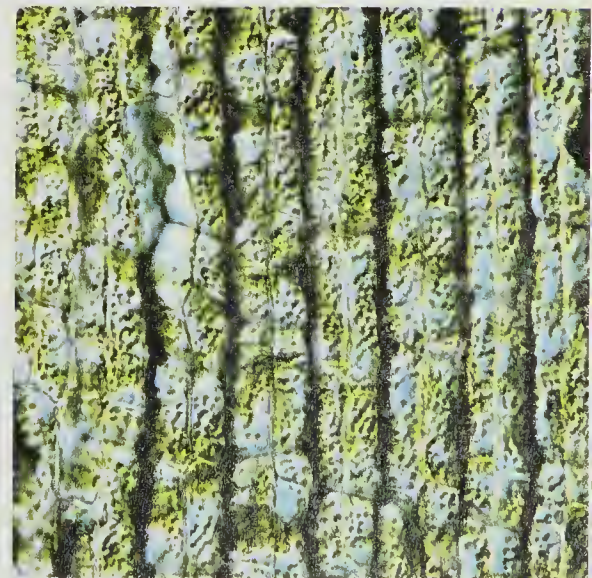
MAIN IDEA

Almost all photosynthesis occurs in chloroplasts, which are made up of grana with stacks of thylakoids surrounded by the stroma.

MAIN IDEA (5-9)

Chlorophyll *a*, chlorophyll *b*, carotene, and xanthophyll are pigments that absorb radiant energy from the sun.

The photograph below shows cells from an elodea plant. Chloroplasts, which can be seen within the cells, contain the pigment chlorophyll.





The beautiful colors of autumn are due to the carotene and xanthophyll pigments in the leaves that are no longer masked by chlorophyll.

Other pigments include the carotenes and xanthophylls, which are red and yellow. Usually these pigments are not seen in plant leaves because they are masked by the green chlorophylls. However, in the autumn, when leaves stop making chlorophyll, the red and yellow pigments become visible and are responsible for the much-admired fall colors. The carotenes and xanthophylls, like chlorophyll *b*, absorb colors that are not absorbed by chlorophyll *a*.

MAIN IDEA

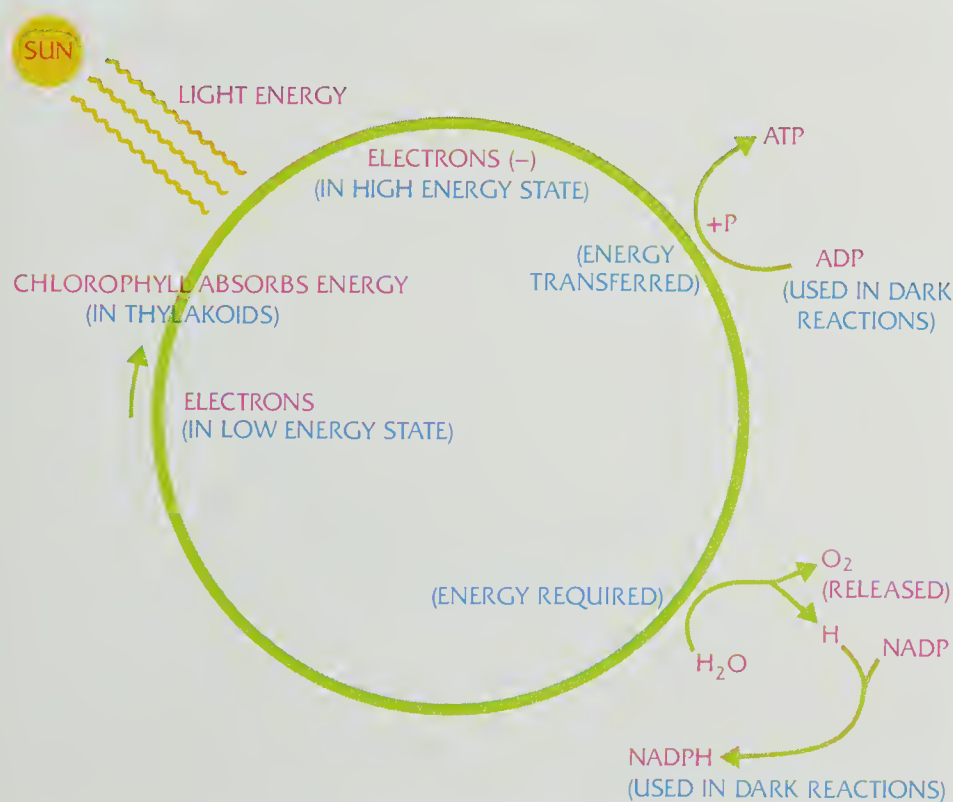
The light reactions of photosynthesis trap radiant energy and convert it to ATP and NADPH. The dark reactions, which do not need light, use ATP and NADPH for energy and carbon dioxide as a raw material for a series of manufacturing reactions.

5–10 The light and dark reactions The process of photosynthesis actually consists of two different series of chemical reactions. One series is called the **light reactions** (rē ak'shənz). In the light reactions radiant energy is trapped and converted to ATP and to an energy storage molecule called **NADPH** (nicotinamide adenine dinucleotide phosphate). Also during the light reactions, water is split into hydrogen and oxygen. The oxygen is a by-product of photosynthesis and is released from the cell.

The second series of reactions during photosynthesis is called the **dark reactions**. They are given this name not because they occur in the dark but because light is not necessary for the reactions to occur. In the dark reactions ATP and NADPH are used for a series of manufacturing reactions. Carbon dioxide is used as the basic raw material in the dark reactions.

5–11 The light reactions The light reactions occur in the thylakoids, where the pigment molecules are concentrated in layers. The radiant energy strikes chlorophyll and causes electrons to be bounced away from the nuclei of certain atoms. If the chlorophyll were in a test tube, the electrons would be pulled back to the nuclei and would give up their energy in the form of fluorescent light. To understand how this occurs, think of pushing a big rock up a hill. That pushing compares to the radiant energy bouncing an electron away from an atomic nucleus. Then picture the rock being released and rolling down the hill. It gives up the energy it had gained. In a like manner an electron bounced away from the nucleus gives up energy as it moves back to the nucleus. This energy is visible in the form of fluorescent light.

In the thylakoid the electrons do not return directly back to the nuclei in the chlorophyll. Instead they pass through a series of chemical reactions in which their energy is transferred to chemical-bond energy. Some energy is stored in the process of **photo phosphorylation**, that is, the process by which light causes ADP to be converted to ATP. Some of the energy and electrons from hydrogens that are split from water molecules are used to make NADPH. Eventually, after useful work has been done by the electrons, they return to the chlorophyll atoms where they can again be bounced away to do useful work.



MAIN IDEA

Light reactions occur in the thylakoids where electrons of chlorophyll are bounced to a higher energy level. The downhill movement of the electrons is used to phosphorylate ATP and to split water to make NADPH.

SCIENCE BACKGROUND

Students sometimes become confused over the terms *fluorescence* and *phosphorescence*. The former is an instant reaction that results from the absorption of light. The latter is a delayed reaction that results in light emission for a period of time after light energy is absorbed.

Actually there are two pigment systems (PS I and II) and an electron transport chain operating during the light reactions. PS I is responsible for reducing NADP; PS II is responsible for catalyzing the removal of electrons from water to produce oxygen.

FIGURE 5–5

During the light reactions of photosynthesis, ATP is generated and water is split into hydrogen and oxygen.

MAIN IDEA

The dark reactions occur in the stroma where CO_2 , ATP, and NADPH are used to make glyceraldehyde phosphate, which, in turn, is used to make simple sugars, fats, amino acids, and different nucleotides.

SCIENCE TERMS

photosynthesis
producers
consumers
chloroplasts
grana
thylakoids
stroma
pigments
chlorophyll
chlorophyll *a*
chlorophyll *b*
light reactions
NADPH
dark reactions
photo phosphorylation
stomata
Calvin cycle

MAIN IDEA (5-13)

Some plants, called C_4 plants, make 4-carbon molecules of malic acid and aspartic acid instead of glyceraldehyde phosphate (C_3 plants). The C_4 plants are primarily of tropical origin and seem to be better adapted to high temperatures and low concentrations of CO_2 .

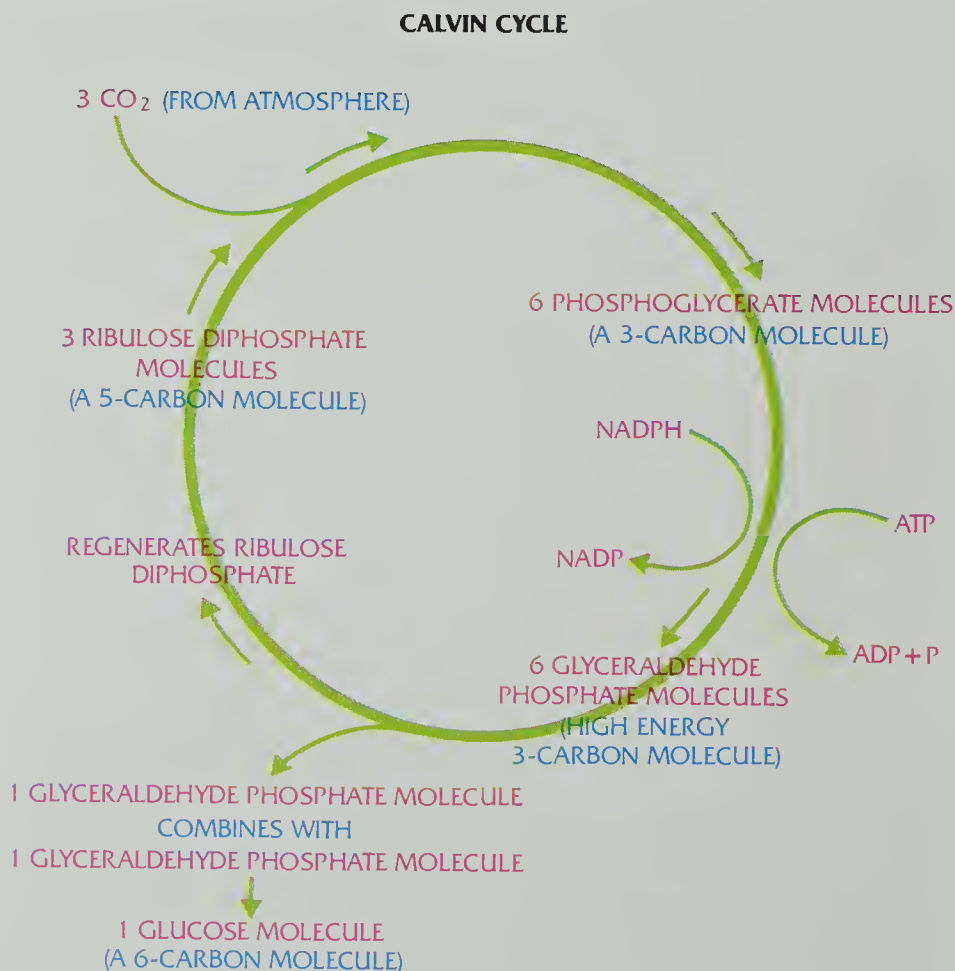
5-12 The dark reactions The dark reactions occur outside the thylakoids in the stroma of the chloroplasts. In the stroma there are teams of enzymes that function somewhat like assembly lines in a factory. Their function is manufacturing, and the energy needed for that work comes from the ATP and NADPH produced in the light reactions.

Carbon dioxide, the raw material used in the dark reactions, enters the leaves of plants through openings called **stomata** (stō mǎ'tə). (Oxygen released during the light reactions also passes out of the leaf through the stomata.) The CO_2 enters a series of reactions called the **Calvin cycle**, named after a University of California professor who first described the cycle.

In the Calvin cycle three molecules of CO_2 react with three molecules of ribulose diphosphate. This results in six molecules of phosphoglycerate, a 3-carbon compound.

In the next reactions ATP and NADPH are used to manufacture six molecules of glyceraldehyde phosphate, which

FIGURE 5-6 During the dark reactions, carbon dioxide is used in the manufacturing of glucose by the cell.



is an energy-rich, 3-carbon sugar. Five of the glyceraldehyde phosphates remain in the Calvin cycle, but one molecule is released. The glyceraldehyde phosphate that is released can be combined with another of its kind to form glucose, a 6-carbon sugar. The glucose, in turn, can be linked to other glucose molecules and stored as starch. The glyceraldehyde phosphate also can be used as a 3-carbon skeleton on which other simple sugars, fats, amino acids, and different nucleotides can be constructed.

5–13 *C₃ and C₄ plants* Recently it was discovered that some plants also convert carbon dioxide into 4-carbon molecules of malic acid and aspartic acid. Now biologists have two names for producers, depending upon which intermediate molecule is produced during the dark reactions. Plants that produce the 3-carbon glyceraldehyde phosphate molecule are known as C₃ plants. Plants that produce the 4-carbon malic acid and aspartic acid are called C₄ plants.

The C₄ plants that have been studied so far are primarily of tropical origin. They include such plants as corn, sugarcane, crabgrass, sorghum, and rice. The C₄ chemical reactions seem to give plants a better chance of surviving under tropical conditions. The enzymes in the C₄ plants work better at higher temperatures and more efficiently with low concentrations of CO₂.

CHECK YOUR FACTS

1. What is a producer? Are you a producer?
2. Explain why consumers are dependent on the sun for their energy.
3. What are the structural units of the grana? What takes place in these units?
4. Name and locate the area where the dark reactions take place.
5. What is a pigment? Why are there several pigments instead of just one?
6. What is the role of the carotenes?
7. What are the products of the light reactions? Are all these used in the dark reactions?
8. Is chemical-bond energy obtained directly from radiant energy? Explain.
9. What are the stomata? What is their function?
10. What does the Calvin cycle accomplish by forming glyceraldehyde phosphate?
11. What are C₄ plants? Where are they found?

ANSWERS TO CHECK YOUR FACTS

1. A photosynthetic organism.
No.
2. Their energy comes from the breakdown of bonds. This energy originated from the sun and was first transformed by a producer.
3. The thylakoids. The light reaction of photosynthesis.
4. The stroma. This is the area of the chloroplast that lies outside the grana.
5. A chemical that absorbs certain color in the visible light spectrum. Since different pigments do not absorb the same colors equally, the total radiant energy absorbed is increased when several pigments are present.
6. They absorb colors not absorbed by chlorophyll a.
7. ATP, NADPH, oxygen, and hydrogen. Not all; the oxygen is released into the atmosphere.
8. No. Radiant energy is converted to the energy stored in displaced electrons. This energy is then released to form chemical bonds.
9. Openings mostly in the leaves through which carbon dioxide and oxygen pass.
10. This is the compound from which sugars, fats, nucleotides, and amino acids are built.
11. A type of plant that produces a 4-carbon molecule in the dark reaction. They are associated with tropical environments because their enzymes are adapted to function well in those conditions.

SCIENCE TERMS

respiration
glycolysis
anaerobic respiration
aerobic respiration

MAIN IDEA

There are two steps in respiration: glycolysis, which is anaerobic; aerobic respiration, which requires oxygen.

ANSWERS TO CHECK YOUR FACTS

1. Respiration is the breakdown of food molecules to provide energy for the cell. It is divided into glycolysis and aerobic respiration, the latter requiring oxygen.
2. No. Yes.
3. The reaction process that makes the four ATP's uses up two of them, leaving a net gain of two.
4. About 10 percent.
5. Carbon dioxide, water, and 36 ATP's per glucose molecule.
6. It means adding an electron.
7. Electrons are removed from NADPH with the energy used to phosphorylate ADP into ATP.

ANSWERS TO REVIEW QUESTIONS

1. An enzyme temporarily bonds the substrate to its active site. This makes the substrate react faster than if no enzyme were present. Upon reacting, the substrate breaks away, leaving the enzyme intact.
2. Enzymes trigger the reactions, thus heat is not needed to start metabolism. Enzymes also control the rate of reaction and convert the released energy gradually instead of all at once, as is the

Respiration

5-14 *Respiration: a double meaning*

Respiration has a double meaning in biology. One use of the term describes the process by which organisms exchange gases between themselves and the atmosphere. In this usage respiration is a synonym for *breathing*.

The second use of *respiration* describes the chemical breakdown of glucose and other food molecules to provide energy for cells.

5-15 Glycolysis There are two major steps in the process of respiration. One step, called **glycolysis** (glī kol'ə sis), occurs in all cells and does not require oxygen. Glycolysis also may be called **anaerobic respiration**, which means "respiration without oxygen."

The process of glycolysis is a series of chemical reactions that breaks the 6-carbon glucose molecule into two 3-carbon molecules of pyruvic acid. In the breakdown of the glucose, four molecules of ADP are phosphorylated into ATP. However, two molecules of ATP are used up in the series of reactions. The net energy gain for the cell is two molecules of ATP. This is less than 10 percent of the available chemical-bond energy in the glucose molecule.

5-16 Aerobic respiration The second major step in the process of respiration is called **aerobic** (ār ō'bik) **respiration** which means "respiration with oxygen." Aerobic respiration is carried out by most but not all cells, and the process requires oxygen. In the eucaryotic cell, aerobic respiration is carried out in the mitochondrion. This is the reason why that organelle is called the "powerhouse" of the cell. Aerobic respiration results in the complete breakdown of pyruvic acid into carbon dioxide and water. The carbon dioxide is picked up by the blood and eliminated through the lungs.

5-17 The net energy result The main function of respiration is to transform chemical-bond energy of food molecules into ATP that can later be used to do the work in the cell. How much useful energy does the process yield?

By itself, glycolysis is inefficient in converting the available energy from a molecule of glucose. Only two molecules of ATP are gained during glycolysis. However, the complete breakdown of two pyruvic acids during aerobic respiration produces 36 ATP's, which results in eighteen times more energy for the cell! The overall useful energy gain from one molecule of glucose that goes through glycolysis and aerobic respiration is 38 ATP's.

CHECK YOUR FACTS

1. What is respiration (the metabolic process), and what are its two stages?
2. Do all organisms use aerobic respiration? Glycolysis?
3. In glycolysis, why is the net gain per glucose molecule two ATP's and not four?
4. About what percent of the chemical-bond energy is utilized in glycolysis?
5. List three end products of aerobic respiration.
6. What do we mean by *reducing a molecule*?
7. What happens during the oxidative phosphorylation reactions?

SUMMARY

All work done by an organism is actually done in the cells. The energy used to do this work is chemical-bond energy. Cells do not require or generate much heat in their chemical, or metabolic, reactions. This is because enzymes act as catalysts to start reactions and as regulators to control the release of energy. ATP is the molecule used to store energy.

REVIEW QUESTIONS

1. Describe how an enzyme functions.
2. How do enzymes enable the cell to metabolize without producing excessive heat?
3. What is phosphorylation? Why is it so important?
4. Describe a chloroplast, explaining where the light reactions and dark reactions take place.
5. Where does aerobic respiration take place? What controls the process?
6. Respiration without oxygen is very inefficient. Explain.
7. What is the net gain of ATP from aerobic respiration? From glycolysis and aerobic respiration?

ANALYSIS AND APPLICATION

1. In what cells of your body would you expect to find large quantities of mitochondria?
2. Organism *X* uses glycolysis as its sole method of food breakdown. What can you guess about the environment, activities, and characteristics of organism *X*?
3. It is believed that the atmosphere of the primitive earth contained no oxygen. What else was probably missing on the primitive earth? Why?

case when a carbohydrate burns in air.

3. The process of increasing the potential energy level of ADP by bonding it with a third phosphate group. The product of phosphorylation, ATP, provides the energy that all cells use to do work.

4. A chloroplast is a green body, or plastid, found in the cytoplasm. Throughout the chloroplasts are bodies called grana, which are made up of discs called thylakoids. It is in the thylakoids that the light reactions occur. Surrounding the grana, with no definite structure, is the stroma. The dark reactions occur there.

5. In the mitochondria. Enzymes.

6. A comparison shows that 18 times more ATP is produced from aerobic than from anaerobic respiration, given an equal amount of food.

7. 36 ATP's. 38 ATP's.

ANSWERS TO ANALYSIS AND APPLICATION

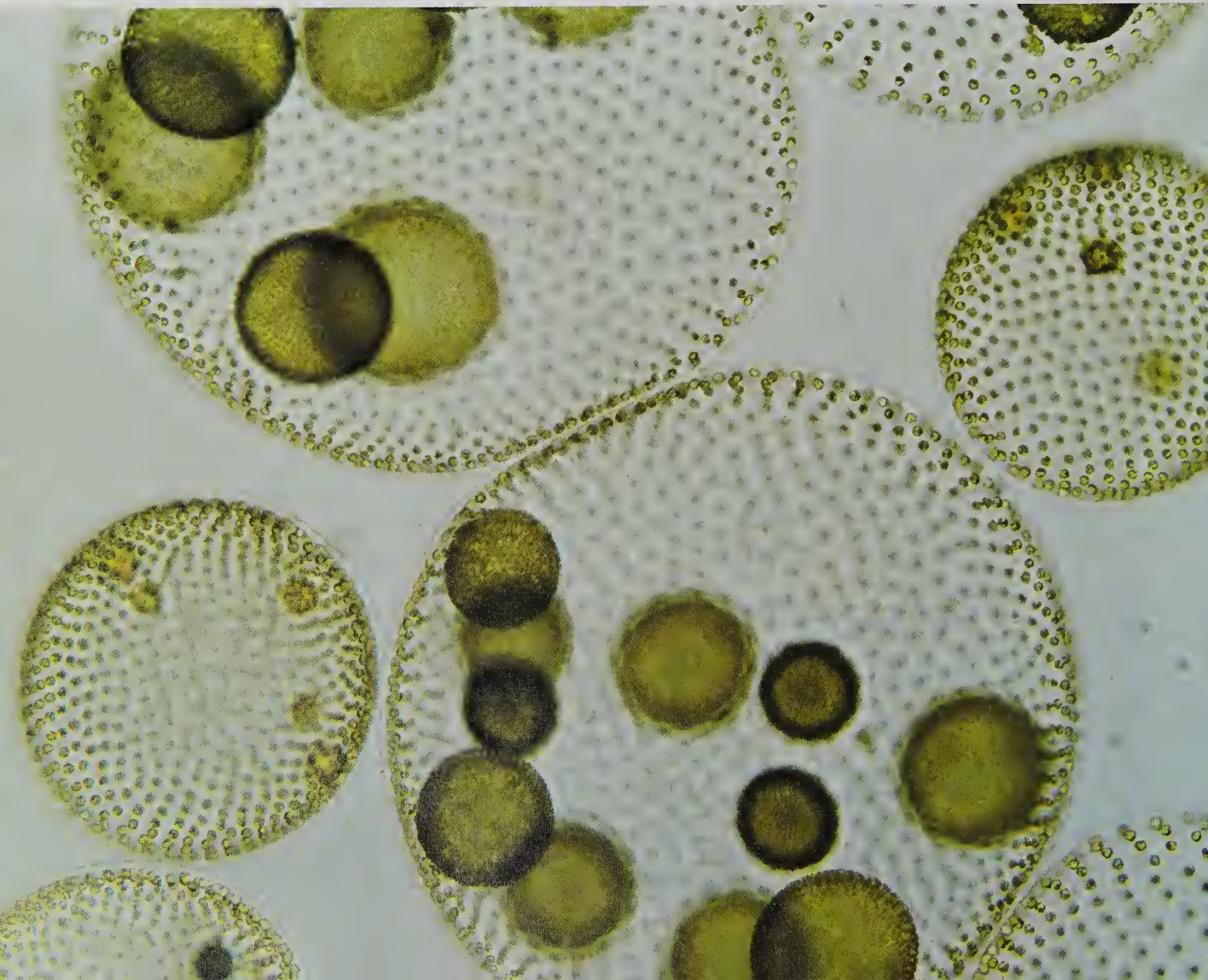
1. In cells that do a lot of work. Muscle cells are obvious examples. They are also abundant in liver cells, which do much biochemical work.

2. Organism *X* requires no oxygen and might live where none is available. Either its food supply is large or it requires little energy to survive, since it can get only two ATP's per molecule of glucose. Organism *X* is probably microscopic and is not green. It does not release water as an end by-product; lactic acid or a similar intermediate is released.

3. Plants, because they would have produced oxygen for the atmosphere, and animals, because they need oxygen to live.

Investigation 15 from *Laboratory Investigations in Biology* can be done with this chapter.

6 *Cell*



OBJECTIVES

- To understand that mitosis is the basic method of cell reproduction
- To state what happens during the interphase of mitosis
- To explain the difference between mitosis and cytokinesis
- To differentiate between the four stages of mitosis
- To appreciate the role of organelle DNA in cytokinesis
- To understand that meiosis is the process of producing haploid gametes
- To know that crossing-over occurs between homologous chromosomes during meiosis
- To understand the two divisions that are involved in the process of meiosis

Reproduction

The Cell Cycle

6–1 The basic method Cells reproduce by **cell division**. In this process, one cell divides into two cells. Each resulting cell, called a daughter cell, is about half the size of the original cell.

A major event that occurs before cell division is the replication of the genetic material, or DNA. In a procaryotic cell there is a replication of the long chromosome that is wound around the inside of the cell. In a eucaryotic cell the chromosomes in the nucleus replicate and are later distributed equally to the two daughter cells. The process by which chromosomes are distributed equally during cell division of eucaryotic cells is called **mitosis** (mī tō'sis).

It is interesting to note that some cells in multicellular organisms never divide after a certain time in the life of the organism. Usually these are cells that are highly specialized. For example, after the human is born, nerve cells and muscle cells do not reproduce themselves. Nerve cells are highly specialized cells that carry information. Muscle cells are specialized to produce movement.

6–2 What is the cell cycle? In cells that are actively dividing, a number of reproductive processes take place with each division. These processes make up the **cell cycle**. The cycle averages about 20 h, from a low of several minutes to a high of several years.

There are two main stages in the cell cycle of eucaryotic cells. The first main stage occurs *after* a cell has divided and *before* the next division occurs. This stage is called **in-**

MAIN IDEA

Cells reproduce by cell division. Replicated DNA is equally divided by mitosis. Many specialized cells reproduce only in the earlier part of an organism's life cycle.

SCIENCE BACKGROUND

Cell division is the basic method of cellular reproduction. It is also called binary fission. Other methods of cell reproduction include budding and the production of spores. A budding cell is smaller than the parent cell. Spores initially are unlike the parent cell.

MAIN IDEA

The processes that are repeated with each cell division make up the cell cycle. This cycle has an interphase before the actual division process takes place.

FIGURE 6–1

The cell cycle can be divided into an interphase stage and a cell division stage.

SCIENCE TERMS

cell division

mitosis

cell cycle

interphase

S phase

G phases

SCIENCE BACKGROUND

For many years interphase was called the resting phase, which was a misnomer because it is now known that interphase is an extremely busy time in the cell involving DNA replication, protein synthesis, and energy transformations.

MAIN IDEA

During the S phase the DNA replicates. Replication occurs simultaneously at several points along the DNA strand.

MAIN IDEA

During the first G phase the cell is readied for the S phase. The second G phase comes after the S phase and includes the final processes before division.



terphase (in'tər fāz). Interphase requires about 19 of the 20 h in the typical cell cycle. The second main stage of the cell cycle is the actual cell division, which usually takes about an hour. Within the two major stages of the cell cycle there are a number of different phases.

6–3 Interphase: the S phase One of the phases of interphase is the synthesis, or **S phase**. During this phase all the nuclear DNA replicates. In human cells and in many animal cells the S phase requires between 6 and 8 h.

In the human cell there are chains of DNA that are about 2 m long. Replication does not begin at one end of a DNA chain and proceed along its length. Replication occurs at the same time at many different places along a chain.

6–4 Interphase: the G phases The phases before and after the S phase are called the gap, or **G phases**. The first G phase, called the G₁ phase, occurs just after cell division and prior to the S phase. The G₁ phase lasts about 8 h. During the G₁ phase certain processes occur in the cell that prepare it for the S phase.

The second G phase occurs after the S phase and is called the G₂ phase. The G₂ phase lasts about 4½ h. The processes necessary for the completion of cell division occur during the G₂ phase. A great increase in the rate of protein synthesis also occurs in this phase.

6–5 Cell division: two stages In eucaryotic cells there are two distinct but overlapping stages of cell division. In the first stage, mitosis, one complete set of chromosomes goes to each daughter cell. Mitosis guarantees that all the genetic information in the nuclear DNA of the parent cell will go to each daughter cell.

In the second stage of cell division the cytoplasm and its contents divide. This process is **cytokinesis** (sī tō ki nē'sis). Cytokinesis is not as precise a process as mitosis. The amount of cytoplasm in a daughter cell will be about half of that in the parent cell. Each daughter cell will have about half of the organelles from the cytoplasm of the parent cell. But there is no precise mechanism working during cytokinesis that *guarantees* each daughter cell will receive exactly half of the parent cell's cytoplasm and its organelles.

CHECK YOUR FACTS

1. What is the cell cycle? How long does it last?
2. What is meant by *interphase*?
3. What occurs during the S phase?
4. What are the two stages of cell division? What occurs in each?
5. In a typical 20 h cell cycle, how long does cell division take?

Mitosis

6–6 The phases of mitosis There are four distinct phases of mitosis: prophase, metaphase, anaphase, and telophase. These phases are well-known because it is possible to observe them with the light microscope.

6–7 Prophase The first phase of mitosis is called **prophase** (prō'fāz). During this phase the invisible threadlike chromatin material of the nucleus condenses into doubled chromosomes, each unit of which is called a **chromatid** (krō'mā tid). In the human cell there are 92 chromatids, which result from replication of the 46 chromosomes during the S phase of interphase. The chromatids are attached at one place, like Siamese twins. The place where they are attached is called the **kinetochore** (ki nē'tō kôr). (The point of attachment is also called the centromere.)

In cells with centrioles, which include all animal cells, the centrioles replicate during early prophase. Later during

MAIN IDEA

Cell division includes mitosis, which divides the chromosomes, and cytokinesis, which divides the cytoplasm.

ANSWERS TO CHECK YOUR FACTS

1. The reproductive processes that are repeated with each cell division. It varies—20 h is typical.
2. The stage in the cell cycle that occurs after cell division and before the next division.
3. The DNA replicates.
4. Mitosis and cytokinesis. In mitosis the genetic information is evenly divided between the daughter cells. In cytokinesis the cytoplasm and its contents are divided imprecisely between the two daughter cells.
5. One hour.

MAIN IDEA

There are four distinct phases of mitosis.

MAIN IDEA (6–7)

During prophase the chromatids appear attached at the kinetochore. Centrioles divide and begin to migrate. The aster and spindle also become visible.

SCIENCE BACKGROUND

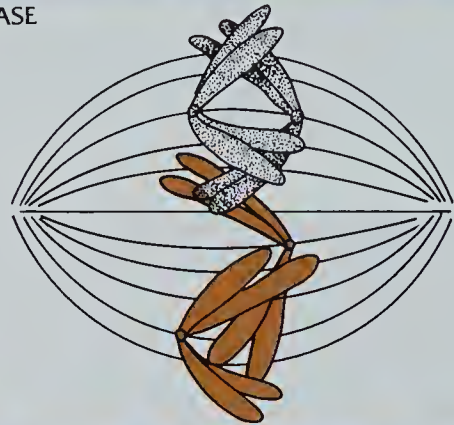
Centriole reproduction begins during the G₁ phase when the centriole pair separates slightly. During the beginning of the S phase, a smaller *pro-centriole* appears, adjacent to each mature centriole. During early prophase the pro-centrioles elongate, separate, and migrate to the poles.



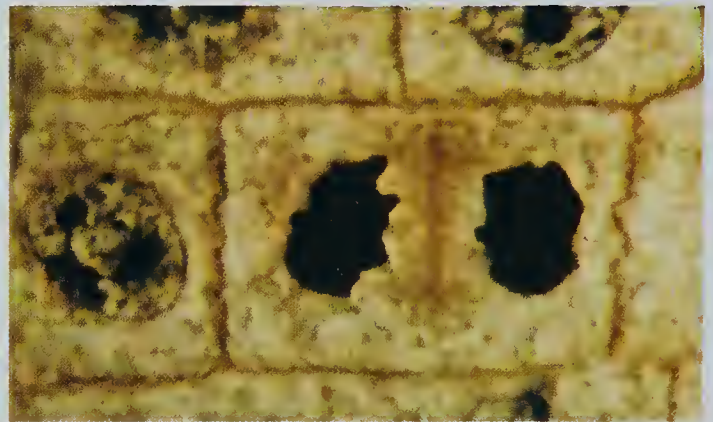
PROPHASE



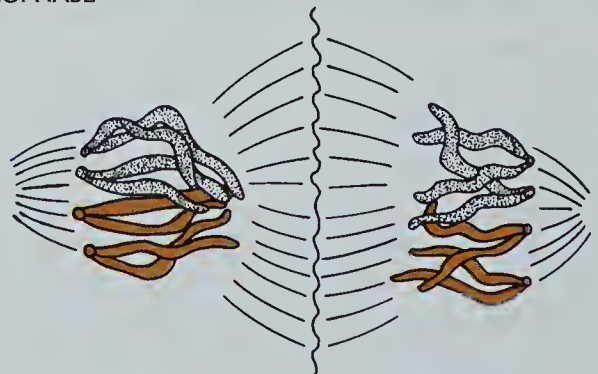
METAPHASE



ANAPHASE



TELOPHASE



The photographs and art above show the stages in mitosis in an onion cell.

prophase the daughter centrioles begin to migrate away from the two parents. Around each centriole, filaments develop and radiate in all directions. These filaments resemble a flower and are called **asters** (as'tərz). During later prophase many of the filaments between the centrioles lengthen and connect with each other. This network of filaments is called the **spindle** (spin'dəl). Late in prophase some filaments of the spindle become attached to the kinetochores, which link the chromatids. In human cells, prophase lasts from 30 to 60 min.

6–8 Metaphase In the second phase of mitosis, called **metaphase** (met'ə fāz), the chromatids become aligned at the midregion, or equator, of the cell. At this time the centrioles, if present, are at opposite ends of the cell. These regions are called the poles.

Also during metaphase the formation of the spindle is completed. Metaphase in human cells requires from 2 to 6 min.

6–9 Anaphase At the beginning of **anaphase** (an'ə fāz), the third phase of mitosis, the kinetochores divide at one time. This causes the chromatids to separate into daughter chromosomes. The daughter chromosomes then move equally to each pole.

6–10 Telophase The fourth stage of mitosis, called **telophase** (tel'ə fāz), begins when all the chromosomes reach the two poles. During telophase the spindle begins to disappear. Later the nuclear membrane reappears and encloses the two groups of chromosomes. While this is happening, the chromosomes begin to disappear as the chromatin material spreads throughout the nucleus.

Cytokinesis also begins during telophase. In animal cells the cytoplasm begins to pinch inward. In plant cells a partition, called the **cell plate**, begins to grow and divide the cytoplasm. Telophase in humans is quite variable, requiring from 30 to 60 min.

6–11 Cytokinesis The preliminary steps of cytokinesis occur during the G phases of the cell cycle. In the G phases various membrane structures, such as the endoplasmic reticulum and Golgi bodies, are produced out of components in the cytoplasm. Therefore, before cytokinesis, there is growth in the size of the cytoplasm and in the number of its organelles.

During the G phases there is reproduction of the mitochondria and chloroplasts. These organelles contain their

SCIENCE BACKGROUND

A multinucleate body is called a *syncytium*. Such a body can result from the fusion of cells or by mitosis without cytokinesis.

MAIN IDEA

The chromatids are aligned at the equator during metaphase. During this period the spindle formation is completed.

MAIN IDEA (6–9)

In anaphase the chromosomes are pulled to the poles after the division of the kinetochores.

MAIN IDEA (6–10)

In telophase the spindle and chromosomes disappear and the nuclear membrane reappears. Cytokinesis also begins at this stage.

MAIN IDEA (6–11)

In most cells, cytokinesis follows division. In the G phase, mitochondria and chloroplasts reproduce and the content of the cytoplasm is increased.

Mitosis in an animal cell is similar to mitosis in a plant cell except that the cytoplasm pinches in instead of a cell plate forming.



SCIENCE TERMS

prophase	metaphase
chromatid	anaphase
kinetochore	telophase
aster	cell plate
spindle	cytokinesis

ANSWERS TO CHECK YOUR FACTS

1. Prophase, metaphase, anaphase, and telophase.
2. One of two units that make up a doubled chromosome. In prophase.
3. A network of filaments that develops from the centrioles. The filaments attach to the kinetochore of the chromatid in late prophase. In anaphase the spindle contracts and pulls the chromosomes toward the poles.
4. The chromatids are positioned along the equator of the cell.
5. Anaphase begins when the chromosomes begin to migrate toward the poles. It ends when all the chromosomes reach the poles.

MAIN IDEA

Meiosis produces gametes that are used to reproduce sexually.

SCIENCE BACKGROUND

Meiosis comes from the Greek term *meioun*, which means “to diminish.”

MAIN IDEA

In meiosis I, sets of homologous chromosomes are divided between the daughter cells. Crossing-over occurs in this phase.

own DNA, called organelle DNA, and their reproduction includes its replication.

Cytokinesis usually starts during telophase and continues after the nuclei of the daughter cells are completely formed. However, cytokinesis does not always occur when mitosis occurs. In some cells, such as those found in certain molds, mitosis occurs repeatedly without cytokinesis taking place. This results in cells with several nuclei.

CHECK YOUR FACTS

1. Name the four phases of mitosis.
2. What is a chromatid? When is this first visible?
3. What is the spindle? What is its role in mitosis?
4. Where are the chromatids during metaphase?
5. When does anaphase begin and end?

Meiosis

6–12 *Cell reproduction for a special purpose*

Cell reproduction occurs for a number of reasons. It occurs in the growing organism and is a part of the growth process. Cell reproduction also occurs when older cells become worn out and die, or when cells are damaged as the result of an injury or disease. A special type of cell reproduction also occurs when organisms reproduce themselves.

During sexual reproduction two reproductive cells, one from each parent, unite to form one cell. That cell then divides and produces a new organism. The reproductive cell, called a **gamete** (gam'ēt), is a unique kind of cell. It contains only one set of chromosomes instead of the two sets that are found in most other cells.

Gametes are produced in the cell reproductive process called **meiosis** (mī ō'sis). Actually cell reproduction occurs twice during meiosis. The net result after two cell divisions is four cells from one cell. Each of the four cells has half the number of chromosomes of the parent cell.

In our discussion of meiosis, we shall distinguish the two cell divisions and their phases by the numerals I and II. To simplify the explanation, we shall describe the process of meiosis as it applies to a cell that has two pairs of chromosomes, or a total of four chromosomes.

6–13 *The first cell division: meiosis I* During prophase I, the first phase of meiosis I, the nuclear membrane disappears and the chromosomes become visible.

The like pairs of chromosomes, called **homologous** (hō mol'ə gəs) **chromosomes**, then do something different from what is observed during mitosis. The homologous chromosomes, each made up of two chromatids attached at the kinetochore, align themselves next to each other. The four chromatids make up a **tetrad** (tet'rad).

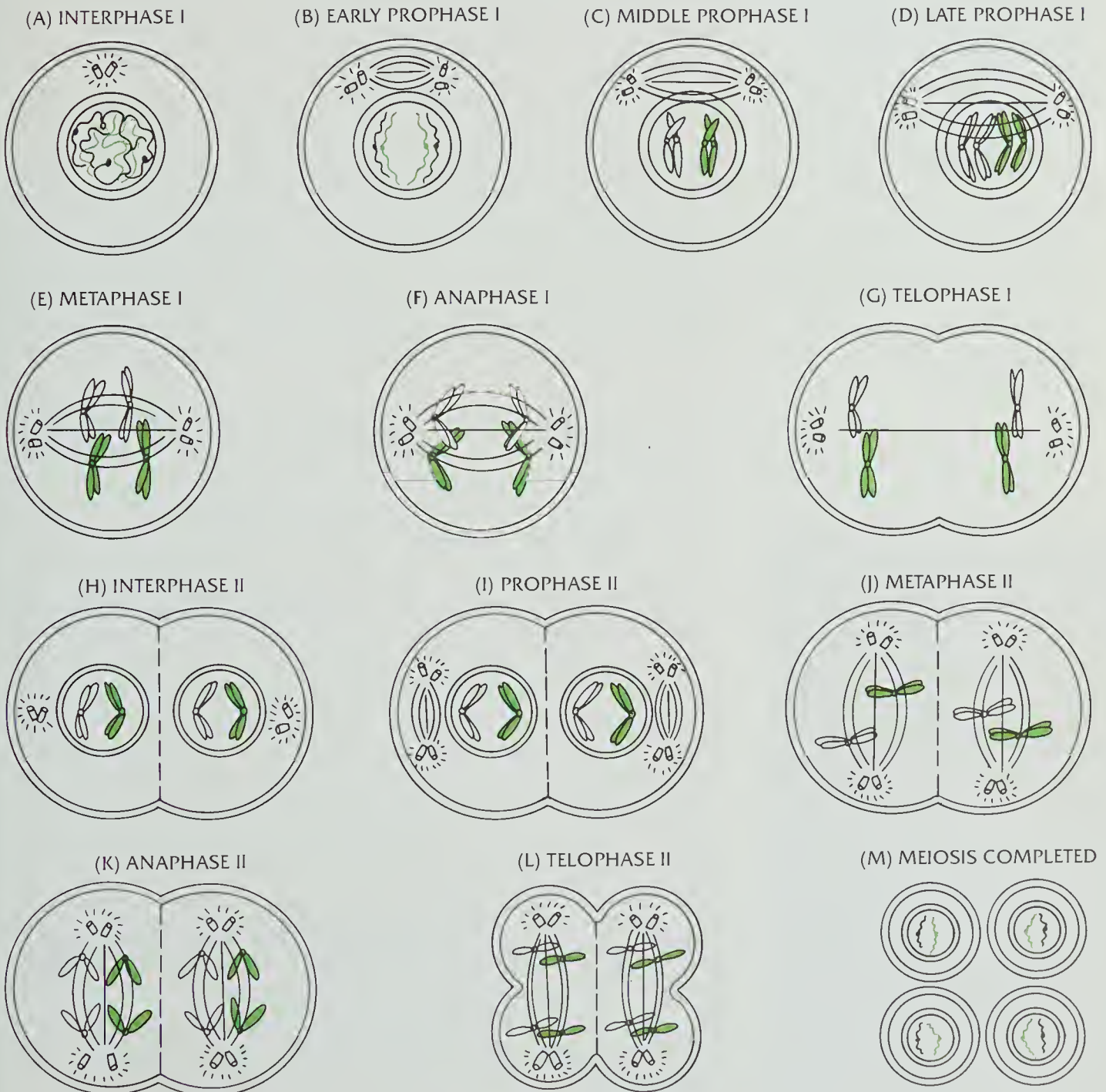
While the four chromatids are close to each other, they often join at places along their length and exchange chromatin. This process is called **crossing-over** and will be discussed in a later chapter.

SCIENCE BACKGROUND

For reasons that are unknown, many higher plants have some cells that have more than their normal complement of chromosomes.

FIGURE 6-2

The stages in the process of meiosis are shown in this figure.



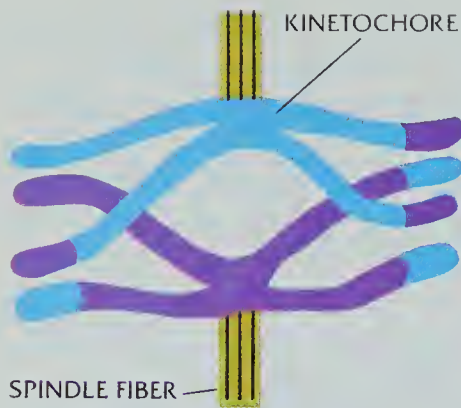


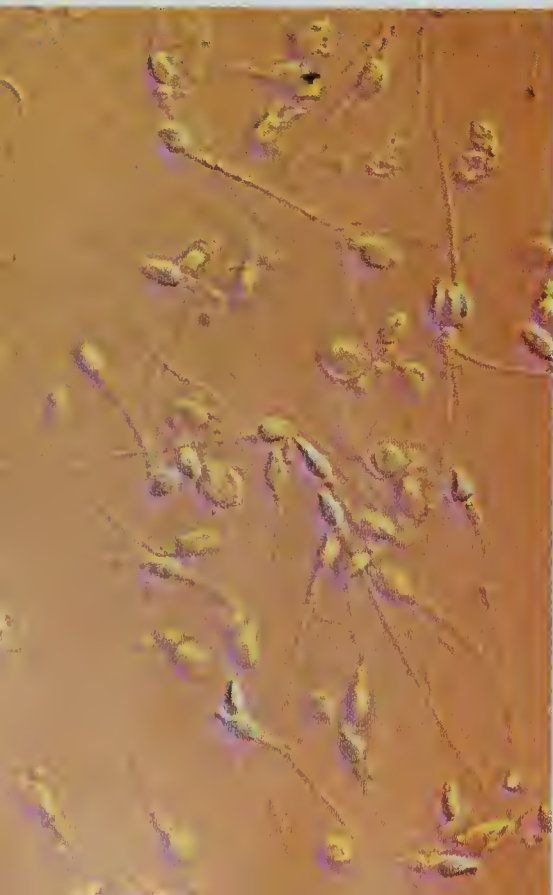
FIGURE 6-3

During prophase I, chromatin material may be exchanged between the chromatids. This is called crossing-over.

SCIENCE TERMS

gamete
meiosis
homologous chromosomes
tetrad
crossing-over
diploid cell
monoploid cell

These sperm cells were produced by meiosis.



At the end of prophase I, in our cell with two pairs of chromosomes, there are eight chromatids arranged in two tetrads. The spindle also has formed, as during mitosis.

In metaphase I the tetrads become aligned along the equator of the spindle. However, the kinetochores do not divide, as they do in mitosis. Therefore, during anaphase I the spindle separates the pairs of homologous chromatids, with one pair going to each pole. Note that the chromatids do not separate during meiosis I.

During telophase I the chromosomes disappear, the nuclear membrane forms, and cytokinesis completes the first cell division. However, DNA replication does not occur in the interphase that follows, as in the normal cell cycle.

6-14 The second cell division: meiosis II

Meiosis II is similar to the process of mitosis. The chromosomes appear and the nuclear membrane disappears during prophase II. During metaphase II two pairs of chromatids become aligned at the equator. However, this time the kinetochores divide, and during anaphase two daughter chromatids are pulled to each pole by the spindle. Telophase occurs as in mitosis, and cytokinesis completes the second cell division.

6-15 The result of meiosis A cell that contains two complete sets of chromosomes is called a **diploid** (dip'loid) **cell**. A diploid human cell contains 23 pairs of chromosomes, or a total of 46 chromosomes.

Meiosis results in four cells, each with only one set of chromosomes. Such a cell is called a **monoploid** (mon'ə ploid) **cell**. (Another name for a monoploid cell is haploid cell.) A monoploid human cell has only 23 chromosomes.

Meiosis solves a major problem for sexually reproducing organisms. It enables gametes to be formed with one set of chromosomes. When those gametes combine during the reproductive process, the total number of chromosomes becomes the proper number for the development of the organism. In humans, two gametes, each with 23 chromosomes, come together and form a new cell with 46 chromosomes. This is the proper number needed for human development. Later, as the new cell divides and mitosis occurs, each resulting human cell will also have 46 chromosomes. Not until the human reaches sexual maturity do special organs in the body begin to produce gametes. Then meiosis produces monoploid cells that contain one half the chromosomes needed to develop a new human being.

CHECK YOUR FACTS

1. What is a gamete? What is the process called that produces a gamete?
2. What is a tetrad?
3. How is anaphase in meiosis I different from anaphase in mitosis?
4. As the cell enters meiosis II, how does it differ from a cell about to divide by mitosis?
5. What is a monoploid cell? How does it compare with a diploid cell?

SUMMARY

Cells reproduce themselves by cell division. Prior to actual division, the DNA replicates. The process by which DNA is equally distributed during cell division is called mitosis. The processes that take place with each division make up the cell cycle. The period between divisions is called interphase. During this time the cell grows, DNA replicates, organelles reproduce, and protein synthesis increases. Cell division consists of mitosis followed usually by cytokinesis. Cytokinesis is the division of the cytoplasm and its contents.

Organisms that reproduce sexually must produce a specialized cell called a gamete. A gamete has only one set of chromosomes instead of the usual two sets. The process by which gametes are produced is called meiosis. Meiosis has two cell-division phases but only one DNA replication. The result is four monoploid gametes from one diploid parent cell.

REVIEW QUESTIONS

1. Distinguish between mitosis and cell division.
2. Do cells divide equally? Explain.
3. How does cytokinesis in plants vary from the same stage in animals?
4. Meiosis is cell reproduction for a special purpose. Explain.
5. How many chromosomes are in a human cell that has resulted from mitosis? From meiosis?
6. Does cytokinesis always follow mitosis? Explain.

ANALYSIS AND APPLICATION

1. Explain why a paralyzed leg resulting from damaged nerve cells cannot heal like a broken leg.
2. If you wanted to count the chromosomes in a cell of a certain kind of plant, where would you look for such a cell?

ANSWERS TO CHECK YOUR FACTS

1. A reproductive cell with one set of chromosomes. Meiosis.
2. Four chromatids that line up together during meiosis I.
3. In meiosis the chromatids do not separate as in mitosis.
4. The DNA has not replicated.
5. Both names refer to a cell with only one set of chromosomes.

ANSWERS TO REVIEW QUESTIONS

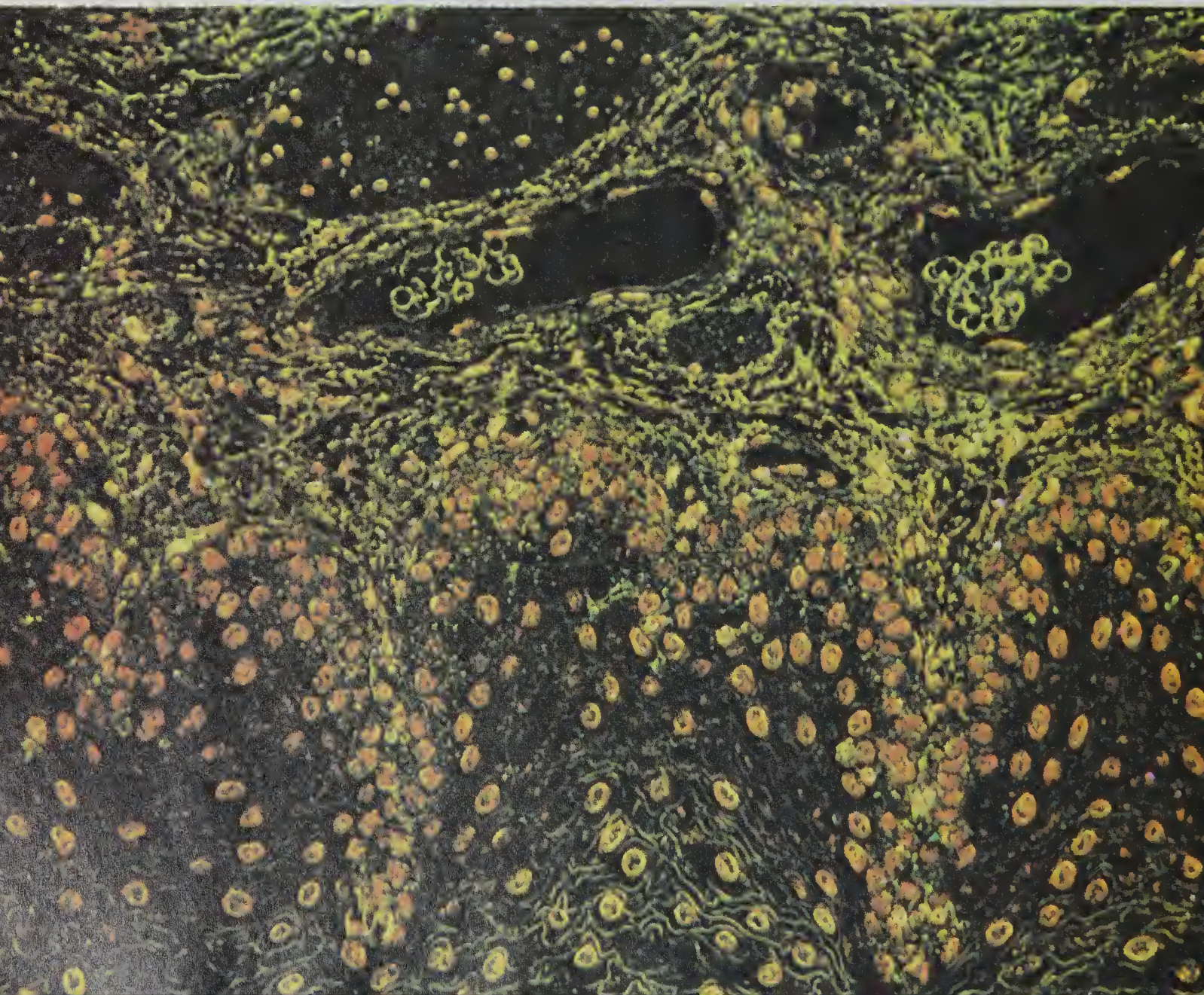
1. They are not the same thing. Mitosis is the process that equally distributes chromosomes between the daughter cells. It is only a part of cell division.
2. No. Cytokinesis divides the cytoplasm and its contents into similar, but not necessarily equal portions.
3. In plants a cell plate is formed to divide the cytoplasm. In animals the cytoplasm pinches inward to separate the cells.
4. Meiosis is only used to reproduce gametes. There are no other uses for the monoploid products of meiotic division.
5. 46, 23.
6. No. In some cells, such as certain fungi cells, repeated mitosis occurs without cytokinesis, resulting in a multinucleate body called syncytium.

ANSWERS TO ANALYSIS AND APPLICATION

1. Nerve cells do not reproduce themselves after an individual is born. Bone cells, however, can reproduce to replace lost or injured cells.
2. In actively growing regions, such as the tips of stems and roots.

Investigations 16–19 from *Laboratory Investigations in Biology* can be done with this chapter.

7 Cellular



OBJECTIVES

- To understand the concept of the concentration gradient and dissolved substances in the cellular environment
- To explain diffusion as a process that results from random molecular collisions
- To describe mass flow
- To understand osmosis and the concept of the selectively permeable membrane
- To predict the direction in which water will diffuse by osmosis when given solute concentrations inside and outside a cell
- To explain how materials too large to pass through the cell membrane may be transported by facilitated diffusion or endocytosis
- To appreciate that substances can move against a concentration gradient
- To understand the process of exocytosis

Traffic

Movement of Liquids

7-1 A busy place Within most cells there are an incredible number of metabolic reactions going on. DNA is replicating, RNA is being formed, and organelles are duplicating themselves. Thousands of proteins are being synthesized and thousands of energy transformation reactions are occurring. For every metabolic reaction, raw materials have to be transported or by-products have to be removed. This means that large amounts of materials have to be moved. Materials must move within the cells. Materials also have to be moved into and out of the cell environment. If it could be seen, the traffic of materials within and around cells would appear far greater than that on the busiest freeways.

7-2 The concentration gradient Every substance is made up of molecules that are in constant motion. In solids the molecular movement is limited to vibrations. In liquids the molecules can move freely throughout the body of the liquid. In gases the molecules are free to move in all directions, and they will fill any container in which they are placed.

In the cellular environment, we are concerned with the movement of liquids and the substances that are dissolved in them. One such type of movement can be shown by placing a drop of food coloring in a glass of water. The particles of food coloring collide with each other and are spread apart by the collisions. The particles of food coloring also collide with the moving water molecules. This also causes them to spread apart.

MAIN IDEA

Many materials must be moved in and out of cells to satisfy the demands of the thousands of metabolic processes.

SCIENCE TERMS

concentration gradient
diffusion
mass flow

When crystals of dye are added to water, they dissolve and eventually spread throughout the water.



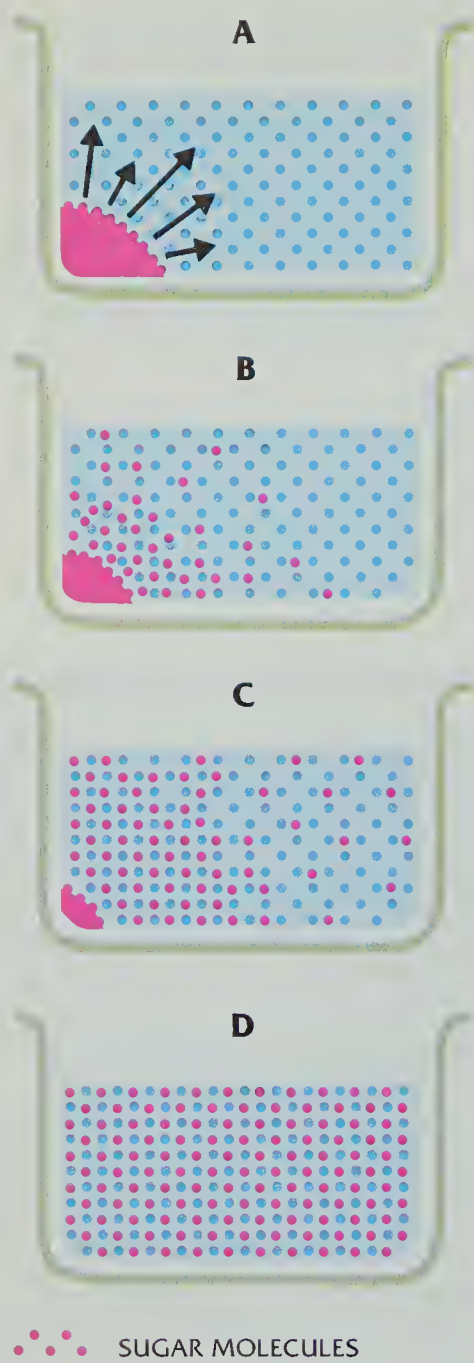


FIGURE 7-1

In the process of diffusion, materials move down a concentration gradient.

ANSWERS TO CHECK YOUR FACTS

1. The difference between areas of high and low concentrations of a substance. The substance will move toward the area of low concentration.
2. The movement of a sub-

The movement of the food-coloring particles in water is random. This means that there is an equal chance that any particle will move in any direction. However, the net movement of the particles is from a region where they are most concentrated to a region where they are less concentrated. The difference between a region of high concentration of a substance and a region of lower concentration of a substance is called a **concentration gradient**. We can liken the concentration gradient to a downhill slope. For example, we say the net movement of the food-coloring particles is *down* the concentration gradient.

7-3 Diffusion The process by which molecular collisions cause a substance to move down a concentration gradient is called **diffusion** (di fyü' zhən). The particles of food coloring are spread throughout water by the process of diffusion. A drop of perfume released in the corner of a room can also be spread throughout the room by diffusion. However, diffusion is a very slow process. Diffusion occurs in the cellular environment, but that method alone is not nearly fast enough to keep the necessary cellular traffic moving. Another process is more effective.

7-4 Mass flow If we placed a drop of food coloring in a glass of very hot water, the particles in the food coloring would spread rapidly. Partly this is because in hot water the molecules move faster, increasing the number of collisions. But more important are the currents in the water, caused by hot water rising and cooler water settling. The currents in the water are an example of **mass flow**, which is the overall movement of a liquid, caused by gravity, pressure, or some other force.

Mass flow accounts for much of the movement of liquids and dissolved substances in the cellular environment. An example of mass flow is the currents that are found in many cells. The currents sometimes run from one region of the cytoplasm to another, like a river. Other currents are short up-and-down movements that cause the cytoplasm to look somewhat like a pot of boiling water.

CHECK YOUR FACTS

1. What is a concentration gradient? How does this determine the direction of movement?
2. What is diffusion?
3. What is mass flow?
4. Which form of transport is more efficient—diffusion or mass flow?

Diffusion Through Membranes

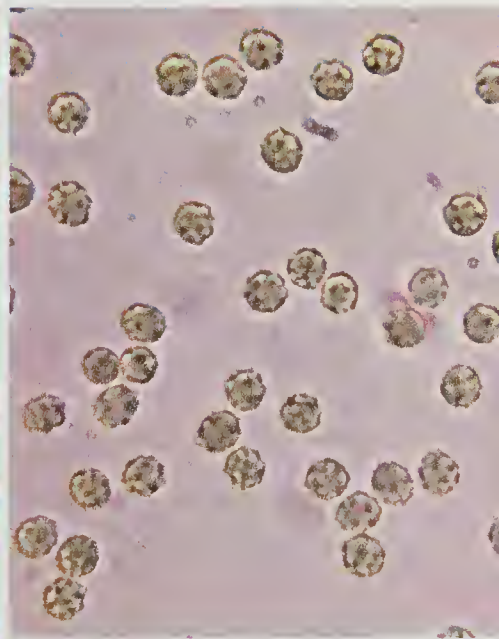
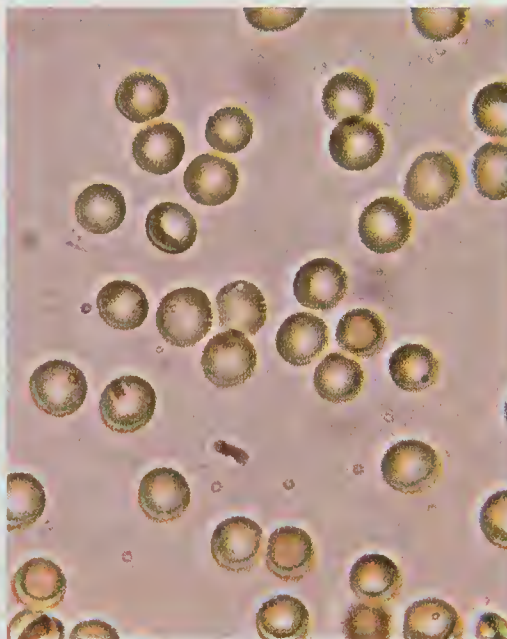
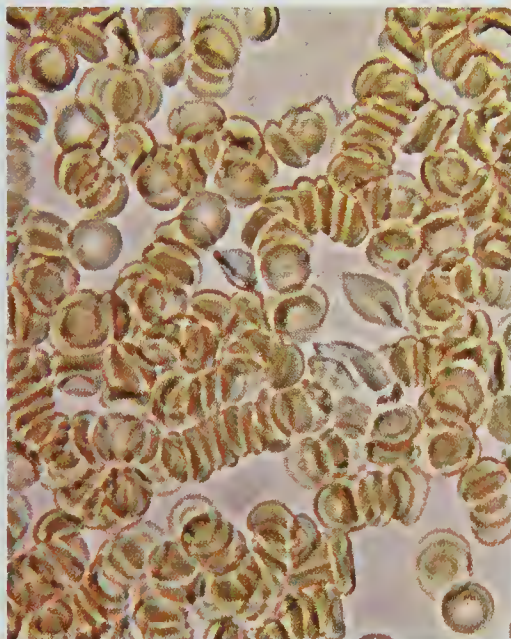
7-5 Osmosis There are many membranes in the cellular environment. The plasma membrane encloses the cell. The nuclear membrane surrounds the nucleus. Each of the organelles is enclosed with a membrane. Some organelles, like the chloroplast and mitochondrion, have membranes throughout their interiors.

Membranes control cellular traffic. They are **selectively permeable** (per'mē ə bəl), which means that they allow only certain materials to pass through them. Water passes through all cell membranes. Substances dissolved in the water may or may not pass through the membranes.

The diffusion of water through a selectively permeable membrane has a special name. The process is called **osmosis** (oz mō'sis).

7-6 Osmosis and concentration gradients It is important to understand how osmosis occurs in cells and organisms. If the concentration of water in the cellular environment varies only slightly, disastrous results can occur. An example is what can happen to red blood cells in human blood. If pure water is added to the blood, osmosis causes the cells to swell up and burst. If a saltwater solution with slightly more salt than found in the red blood cells is added, osmosis causes the red blood cells to shrink. Can you explain this difference?

Normal red blood cells are shown at left. Red blood cells will swell if placed in pure water (middle). They will shrink in salt water (right).



stance down a concentration gradient.

3. A movement of a liquid caused by an external force.

4. Mass flow.

MAIN IDEA

Osmosis is the diffusion of water through a selectively permeable membrane.

SCIENCE BACKGROUND

Some biologists will argue that the old terms *semipermeable*, or *differentially permeable*, should be used to describe the plasma membrane. We think the more recently coined term *selectively permeable* is more appropriate.

MAIN IDEA

Osmosis occurs along a concentration gradient. Because of osmosis, dissolved substances in water can have a great effect on cells.

SCIENCE BACKGROUND

The teacher may wish to introduce terms that describe the relationship between two water solutions. If the two solutions have an equal number of solute particles dissolved in them, they are *isotonic*. A solution with fewer particles of solute than another solution is *hypotonic*; a solution with more particles of solute than another is *hypertonic*.

SCIENCE TERMS

selectively permeable
osmosis

MAIN IDEA

Plants can be killed by adding enough chemicals to the surrounding water to reverse the concentration gradient.

SCIENCE BACKGROUND

Students in suburban and rural areas will have observed the effect of dog urine on grass and shrubs—an effect similar to overfertilization.

Some single-celled organisms, such as the paramecium, are hypertonic to the surrounding water, which causes the net movement of water to be toward the interior of the cell. The paramecium solves the problem with its contractile vacuole, which is a pump that is constantly bailing out surplus water.

Like all forms of diffusion, osmosis occurs along a concentration gradient. The example of osmosis and red blood cells shows how a change in the concentration gradient can change the direction of osmosis. Inside red blood cells there is a saltwater solution. The solution is about 0.9 percent, which means that for every 100 mL of water there is 0.9 g of dissolved salt.

If pure water is added to the outside environment of a red blood cell, will the concentration gradient of the water be toward the inside or outside of the cell? The concentration gradient will be toward the inside of the cell. The reason is that there is a greater concentration of water outside the cell than inside the cell. Osmosis will cause more water to enter the cell than to leave it. The cell will swell, and eventually the expansion will rupture the plasma membrane, causing destruction of the cell.

Suppose a 2 percent saltwater solution is placed outside the red blood cell? Now the concentration of water is greater inside the cell than outside the cell. Osmosis will cause water to flow out of the cell into the outside environment. The cell volume will decrease. The cell will shrink.

7-7 Osmosis and plants Normally the concentration gradient around plant roots is toward the root cells. Thus osmosis causes water to move from outside the plant into the roots. Now you can understand how plants can be killed by pouring a saltwater solution on them. A saltwater solution can change the concentration gradient so that osmosis occurs in the opposite direction. Water diffuses outward from the roots, causing the plant to wither and eventually die.

FIGURE 7-2 If the concentration gradient around a plant cell is toward the outside, osmosis will cause water to leave the cell and it will shrink.



Overfertilization also can cause plants to die for the same reason. The fertilizer, when dissolved in the water in the soil, can change the concentration gradient so that osmosis drains water from the plant. One way to save plants that have been overfertilized is to add large quantities of water so that the fertilizer becomes diluted. If diluted enough, the concentration gradient can be changed so that there is a greater concentration of water outside the plant roots. Then osmosis will occur in the proper direction.

CHECK YOUR FACTS

1. How do membranes in the cellular environment control traffic in the cell?
2. What is osmosis? How is it affected by the concentration gradient?
3. If salt is added to the water surrounding a cell, what might happen to the cell?
4. In the cell mentioned above, is any water moving into the cell after the salt is added?
5. Why can a saltwater solution kill a plant?

ANSWERS TO CHECK YOUR FACTS

1. They are selectively permeable.
2. Diffusion of water through a selectively permeable membrane. The concentration gradient determines the direction of osmosis.
3. Water will leave the cell, causing the cell to shrink.
4. Yes. Individual water molecules move randomly. The net flow, however, is from the cell to the environment.
5. It can reverse the concentration gradient. This causes the plant to lose its water to the surrounding environment.

Other Forms of Cell Transport

7–8 Facilitated diffusion Glucose and some other raw materials needed by the cell cannot diffuse through the plasma membrane. Then how do they get inside the cell? One method, called **facilitated** (fə sil'ə tā tid) **diffusion**, makes use of a carrier molecule. A molecule such as a protein, which can pass through the plasma membrane, temporarily binds itself to a molecule of glucose. The protein-glucose combination molecule moves into the cell, where the glucose is then released. Biologists are not sure how a giant molecule like a protein gets through the plasma membrane but the much smaller glucose molecule by itself cannot.

7–9 Active transport Some cells are able to move substances across the plasma membrane against a concentration gradient. This process is called **active transport**. Active transport occurs in the cells that line the human small intestine. Molecules such as amino acids and glucose continually diffuse into the cells, even though there is a greater concentration of them outside. Carrier molecules are used during active transport. Also, energy in the form of ATP is necessary to move materials against a concentration gradient.

MAIN IDEA

Facilitated diffusion involves the use of a carrier molecule, which enables a substance to pass through a membrane.

SCIENCE TERMS

facilitated diffusion
active transport
phagocytosis
pinocytosis
endocytosis
exocytosis

MAIN IDEA

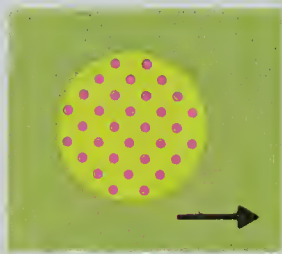
Movement of substances against a concentration gradient requires energy and is called active transport.

ANSWERS TO CHECK YOUR FACTS

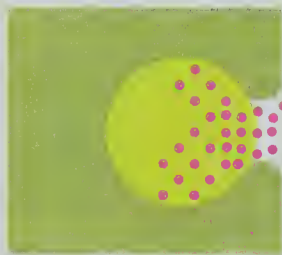
1. A substance can pass through a membrane when bonded to a carrier molecule.
2. The process of moving substances across a membrane against a concentration gradient. Energy.
3. In the small intestine.

FIGURE 7-3

Through the process of exocytosis, material within the cell can be released into the outside environment.



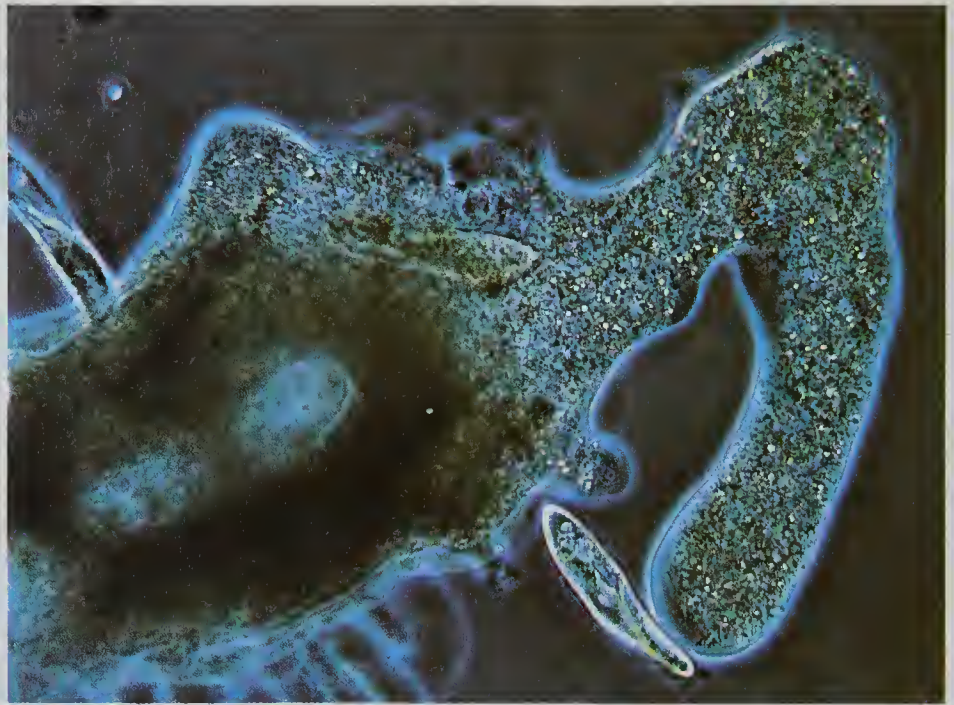
A vesicle containing material to be secreted approaches the cell envelope



and fuses with it so the inside of the vesicle becomes continuous with the outside of the cell



and the vesicle's contents can be deposited outside.



This amoeba is consuming paramecia by the process of phagocytosis. One paramecium has already been ingested.

7-10 Endocytosis Another way substances can move across the plasma membrane is in vacuoles, which are cavities within the cell. An example is the process of **phagocytosis** (cell eating) by which cells take in solid objects. During phagocytosis the plasma membrane surrounds an object and eventually encloses it, forming a vacuole. Then the vacuole is released from the plasma membrane and moves to the interior of the cell. A similar process, called **pinocytosis** (cell drinking), enables the cell to take in materials in liquid solutions. Sometimes both processes, phagocytosis and pinocytosis, are together described by the term **endocytosis** (en dō sī tō'sis).

7-11 Exocytosis Cells also can export materials across the plasma membrane in vacuoles. This process is called **exocytosis**. In exocytosis the vacuole forms inside the cell. It migrates to the edge of the cell and fuses with the plasma membrane. Then the membrane around the vacuole separates, and the object is released outside the cell.

Exocytosis is the process by which most proteins are probably exported from cells where they are synthesized. They are first "packaged" inside the sacs of the Golgi apparatus. Then the sacs, which are large vacuoles, separate from the Golgi apparatus and move to the plasma membrane, where they are released.

CHECK YOUR FACTS

1. Describe *facilitated diffusion*.
2. What is active transport? What is required to achieve it?
3. Where might one find active transport in the human body?
4. What are two types of endocytosis? What distinguishes them?
5. What cell structure is a product of endocytosis?
6. Describe exocytosis.
7. In what organelle are proteins for export by exocytosis enclosed in vacuoles?

SUMMARY

For each of the thousands of metabolic reactions in a cell, raw materials and finished products must be transported. Movement must occur within a cell as well as between the cell and its environment.

Molecular collisions cause diffusion, the simplest mode of transport. Diffusion moves substances down a concentration gradient from areas of high concentration to areas of lower concentration. A more efficient method of transport is mass flow, which is the overall movement of a liquid caused by a physical force, such as gravity or pressure. Osmosis is the diffusion of water through a selectively permeable membrane.

REVIEW QUESTIONS

1. What is the function of a selectively permeable membrane?
2. What is osmosis? Can salt be transported by osmosis?
3. What would happen to a freshwater organism that was placed in a saltwater solution? Explain.
4. Is size the only factor that determines whether or not a molecule will pass through the plasma membrane? Explain.
5. How does active transport differ from diffusion?
6. Why does diffusion occur? Why is diffusion less effective in organisms than mass flow?

ANALYSIS AND APPLICATION

1. Can you think of an advantage of endocytosis over other forms of transport across cell membranes?
2. What might you do to a lawn that has been overfertilized to save it from drying out or "burning"? Why might your technique work?

4. Phagocytosis and pinocytosis. The former is taking in solids, the latter involves liquid intakes.

5. Vacuole.

6. Substances enclosed in vacuoles migrate to the plasma membrane. The vacuole ruptures, and the contents enter the cell environment.

7. Golgi apparatus.

ANSWERS TO REVIEW QUESTIONS

1. It allows certain substances to pass through, while screening out others.
2. The diffusion of water through a selectively permeable membrane. No.
3. The concentration of water inside the cell would be greater than outside the cell. Water would leave the organism and the organism would shrink.
4. No. Proteins are much larger than glucose molecules yet can cross the membrane unaided, while glucose cannot.
5. Substances in active transport are moving against the concentration gradient. This requires an energy source.
6. Molecules collide. These collisions tend to spread molecules away from the area of highest concentration. Diffusion is much slower than mass flow.

ANSWERS TO ANALYSIS AND APPLICATION

1. Large bodies of material can be taken into cells by endocytosis.
2. Water the lawn heavily to dilute the fertilizer and to increase the concentration of water outside the plant roots. This might keep the concentration gradient of the water toward the inside of the roots.

UNIT 1 REVIEW

1. Botany, zoology, and microbiology are the major branches of biology. However, there are many specialized branches in addition to these. Find out what the following specialized branches of biology are concerned with: cytology, histology, embryology, physiology, anatomy, pathology, mycology, ornithology, herpetology, endocrinology.
2. Jane van Lawick-Goodall is a well-known biologist in the field of animal behavior. Find out what animals she has been studying. What biological methods are important in her works?
3. Many scientists made important contributions to the cell theory. Using library facilities, write a report on the contributions of one of the following: René Dutrochet, Matthias Schleiden, Theodor Schwann.
4. Read about the experiments of Francesco Redi and Louis Pasteur dealing with spontaneous generation. Under the supervision of your teacher, set up a similar experiment to test the theory of spontaneous generation in your laboratory.
5. With your teacher's permission and supervision, examine slides of plant and animal cells from the school's collection. Make sketches and label any structures that you can identify.
6. What are some structural differences between plant cells and animal cells? What are some structural similarities?
7. A strand of DNA has the following sequence of bases: guanine — thymine — guanine — adenine — cytosine — cytosine — thymine — guanine — adenine — adenine — guanine — cytosine. Determine the base sequence of the complementary strand of DNA. Determine the base sequence of a strand of RNA produced from the first strand of DNA.
8. What are the different roles of mRNA, rRNA, and tRNA in the cell?
9. Why is there some controversy connected with recombinant DNA research? Find out what actions have been taken by government and scientific leaders concerning this controversy.
10. How do enzymes function in cells? Make a sketch of enzyme action to help clarify your explanation.
11. Why is photosynthesis of such importance to all forms of life on earth?
12. With your teacher's permission and supervision, examine slides of plant and animal mitosis from the school's collection. Sketch and identify the various stages.

Unit 2

CONTINUITY OF LIFE



In the mid-1800s the German biologist Rudolf Virchow made a statement about life that can serve to introduce this unit. He said that every cell can originate only from another cell. Therefore, every cell in every organism that is alive today has come from cells that were in organisms that are no longer alive. Also, the cells that are the ancestors of today's organisms came from organisms that lived further in the past. Thus, there has been a continuous stream of life through the ages—a continuity. This unit explains how and why this continuity of life occurs.

Investigation 20 from *Laboratory Investigations in Biology* can be done with this chapter.

8 *How Traits*



OBJECTIVES

- To describe Mendel's experiments with garden peas
- To appreciate how Mendel used elementary probability theory to account for the results of his crosses
- To develop the skill of diagramming and analyzing monohybrid and dihybrid crosses using probability arithmetic
- To understand the difference between genotype and phenotype
- To know the expected ratios of phenotypes from the monohybrid and dihybrid crosses
- To discuss the role of *Drosophila* in genetics research
- To know that recessive genes on the X chromosome will be expressed like dominants in the male
- To understand the concepts of incomplete dominance and codominance
- To understand that multiple alleles can cause a number of varieties of a given trait

Are Inherited

Mendel's Early Experiments

8-1 The science of genetics Young sponges, alligators, pine trees, and humans resemble their parents. Why? Because every parent gives its offspring at least one set of genes from its own body. You will recall from Chapter 4 that a gene is a section of a DNA molecule that contains instructions for building one part of a protein. A total set of genes contains instructions for building all the proteins in an individual's body. Some proteins make up much of the structure of an individual. Many other proteins are enzymes that control most functions in individuals. Therefore, the genes that come from parents largely determine the structure and function in a new individual. That is why young sponges, alligators, pine trees, humans, and all other organisms resemble their parents.

There is a specialized branch of biology devoted to the study of genes and how they interact with each other in the development of new organisms. That branch of biology is called **genetics** (jə net'iks). Genetics began in the mid-1800s in a small town in what is now Czechoslovakia. The founder of the science was an Augustinian monk named Gregor Mendel.

8-2 Mendel and garden peas In the mid-1800s nothing was known about DNA or genes. Nor were any facts known about the inheritance of characteristics from parents to offspring. Gregor Mendel changed all that. Over a period of years, he carried out a series of experiments in the gardens of his monastery. He experimented by breed-

MAIN IDEA

Genetics is the study of genes and their role in development.

Gregor Mendel's work with garden peas laid the foundation for the science of genetics.



MAIN IDEA

Mendel selected the garden pea for his experiments because he could control fertilization and there were several varieties that were true-breeding.

MAIN IDEA (8-3)

In his first experiments Mendel crossbred varieties with contrasting characteristics.

MAIN IDEA (8-4)

The results of the 1st cross showed the survival of only one of the contrasting traits. He called these dominant traits.

MAIN IDEA (8-5)

The recessive traits absent in the F_1 generation reappeared in the F_2 generation in a 3:1 ratio of dominant to recessive traits.

SCIENCE BACKGROUND

Gregor Mendel was born on July 22, 1822, in Moravia, in central Europe. His father was a peasant who labored three days a week on a manor. It is reported that a countess took a special interest in the local school and encouraged the teaching of science, which was not part of the state curriculum. A dedicated teacher, Thomas Makitta, probably inspired Mendel at an early age.

Mendel studied at the University of Vienna, where he became interested in statistics and botany. This led to the series of experiments that were to establish the new science of genetics.

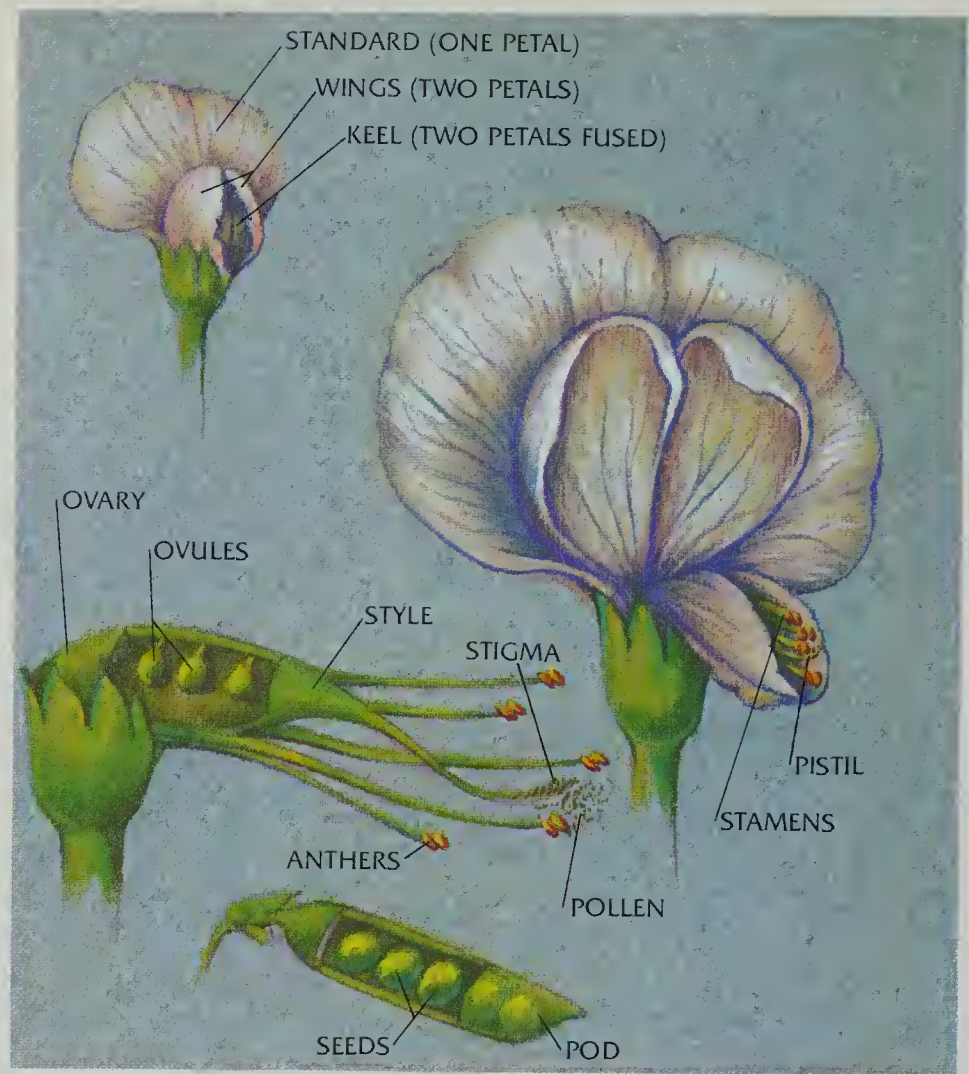


FIGURE 8-1 This figure shows the structure of the garden pea flower that Mendel used in his experiments.

ing the garden pea. He selected the garden pea because there were at least 34 different varieties that he could purchase at that time. Also the garden pea had an advantage over other plants because of its unique flower. The reproductive organs in the flower are enclosed, so that insects do not normally reach them. Each flower normally fertilizes itself. This means that the male and female gametes, which contain the genetic information, unite within the flower in which they are produced. In flowers that are cross-fertilized, the male gametes are usually carried by wind or insects to other flowers.

Before starting his experiments, Mendel raised several varieties of garden peas to be sure that they would breed "true." In other words, he made sure that a variety that was supposed to produce yellow peas did, indeed, produce yellow peas all the time.

8-3 Mendel's first experiments Mendel's first experiments were crossbreeding experiments. He collected pollen, which contained the male gametes, from one variety of garden pea and placed it on the female reproductive organs of another variety of garden pea. The male gametes fertilized the female gametes, resulting in fertilized egg cells. Each fertilized egg cell resulting from the cross-fertilization developed into a seed containing a small new plant. Each new plant contained genetic information from both parents.

In his first crossbreeding experiments, Mendel crossed varieties that had two contrasting characteristics, or **traits**. For example, he crossed a variety that produced *round* seeds with a variety that produced *wrinkled* seeds. A few months later, when he examined the offspring of this cross, called the **first filial generation (F₁)**, he found some surprising results.

8-4 The results of Mendel's first experiments When Mendel examined the seeds that were produced by the *round-wrinkled* cross, he discovered that all the seeds were *round*. None were *wrinkled*. Likewise, when he examined the results of other crosses, he found that only one trait survived in the offspring. For example, in the cross between a *yellow* pea variety and a *green* pea variety, all the seeds were yellow.

The traits that appeared in the F₁ generation Mendel called **dominant** (dom'ə nənt) traits. The traits for *round* and *yellow* seeds were dominant traits. The other traits—those that seemed to disappear after the first crossbreeding experiment—were called **recessive** (ri ses'iv) traits. The traits for *wrinkled* and *green* seeds were recessive traits.

8-5 The F₁ cross The next year Mendel planted the seeds of the F₁ generation and let them fertilize themselves. Later, when he examined the mature plants and their seeds, he found surprising results. The recessive traits had not disappeared after all. The *round* seeds of the F₁ generation produced both *round* and *wrinkled* seeds. Likewise, the F₁ *yellow* seeds produced plants that grew both *yellow* and *green* seeds.

Such results would probably have confused most plant breeders. However, Mendel had been trained in mathematics and he thought in terms of numbers and statistics. He decided to count and tabulate the thousands of peas that resulted in the **second filial generation (F₂)**—the offspring of the F₁ generation. The results of his work were startling. There was a definite ratio between the two traits



FIGURE 8-2

Some of the traits that Mendel studied in his experiments on garden peas are shown in this figure.

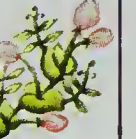
Mendel's Results with Two Generations of Garden Peas				
Traits Selected For Cross	F_1 Plants	F_1 Self-pollination	F_2 Plants	Actual F_2 Ratio
 X 		 X 	5 474 round seeds 1 850 wrinkled seeds 7 324 Total	2.96:1
 X 		 X 	6 022 yellow seeds 2 001 green seeds 8 023 Total	3.01:1
 X 		 X 	705 gray seed coats 224 white seed coats 929 Total	3.15:1
 X 		 X 	882 inflated pods 299 wrinkled pods 1 181 Total	2.95:1
 X 		 X 	428 green pods 152 yellow pods 580 Total	2.82:1
 X 		 X 	651 axial flowers 207 terminal flowers 858 Total	3.14:1
 X 		 X 	787 long stems 277 short stems 1 064 Total	2.84:1

FIGURE 8-3 When Mendel tabulated the result of his F_2 generation, he found a 3 to 1 ratio of dominant to recessive traits.

in the F_2 generation. In Figure 8-3 you will see that the ratio between dominant and recessive traits was about 3:1. For every three peas with the dominant trait, there was one with a recessive trait.

MAIN IDEA

Mendel used probability theory and letter symbols to help analyze the results of his breeding experiments.

8-6 Trying to explain the results For many scientists the most interesting part of an experiment is attempting to explain the results that are obtained. Mendel must have enjoyed the challenge of trying to explain his F_2 generation.

Mendel probably borrowed an idea from his training in algebra when he used letter symbols for the different traits of the garden peas. We will follow his practice, using a capital letter (**R**) to symbolize the dominant *round* trait and a small letter (**r**) for the recessive *wrinkled* trait.

We know that Mendel began to think in terms of **probability** (prob ə bil'ə tē). Probability is the branch of statistical arithmetic that tries to predict the results of chance events.

8-7 Probability A simple way to understand probability is to try to predict the result of tossing a coin, which is a chance event. There is an equal chance of tossing a head or a tail. Thus there are two possible results, and the probability of either result occurring is expressed as a fraction. The numerator of the fraction is the number of results that are expected. The denominator is the number of results that are possible. Therefore the probability of a coin landing a head or a tail after the first toss is expressed as the fraction $\frac{1}{2}$ —one result is expected and two results are possible.

It is important to realize that probability statements are not accurate predictions. A tossed coin might land heads five times in a row. But the probability of tossing a head the sixth time is still $\frac{1}{2}$.

A fact to remember about probability is that the predictions have a better chance of being accurate when there are a large number of events. For example, if you flip a coin 10 times, the result could easily be six heads and four tails. But if you flip a coin 1 000 times, the results are not likely to be 600-400. The results are much more likely to be nearer the $\frac{1}{2}$ probability, or closer to 500-500.

8-8 Probability and Mendel's F_1 generation Mendel reasoned that the gamete of each parent contributes some inheritance "factor" to every offspring for every trait. Thus he reasoned that a true-breeding *round* variety of garden pea would contribute an **R** from the male and an **R** from the female. Offspring produced from true-breeding parents with *round* seeds would be described as **RR**. Likewise, offspring from true-breeding parents with *wrinkled* seeds would be described as **rr**.

Using symbols and probability, Mendel next diagramed a cross between two true-breeding varieties:

$$\mathbf{RR} \times \mathbf{rr}$$

In the cross, each parent contributes one gamete. From the **RR** parent the gamete can contain either an **R** or an **R** because both factors are alike. The same applies to the **rr** parent, which can contribute gametes with an **r** or an **r**. See Figure 8-4. Therefore, in the cross between the **RR** and **rr**, which are chance events, the probability for each offspring is shown on the following page.

MAIN IDEA

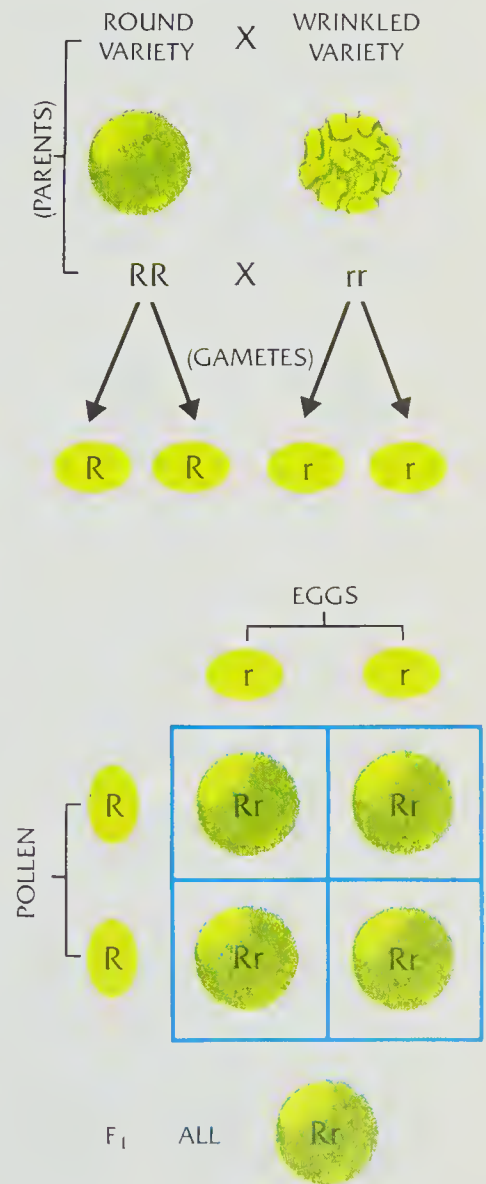
The probability of an event is expressed as a fraction—the numerator is the number of expected results and the denominator is the number of possible results.

MAIN IDEA (8-8)

Mendel hypothesized that his F_1 generation all carried both the dominant and the recessive factors and all showed the dominant trait.

FIGURE 8-4

If a plant that breeds true for a dominant trait is crossed with one that breeds true for a recessive trait, only the dominant trait appears in the F_1 .



MAIN IDEA

Mendel reasoned that the F_2 generation consisted of plants that had two copies of either the dominant or the recessive factor and plants that had one of each. Probability indicates that $\frac{1}{4}$ of the plants should have two recessive factors, thus explaining the 3:1 ratio.

SCIENCE TERMS

genetics

traits

first filial generation (F_1)

dominant

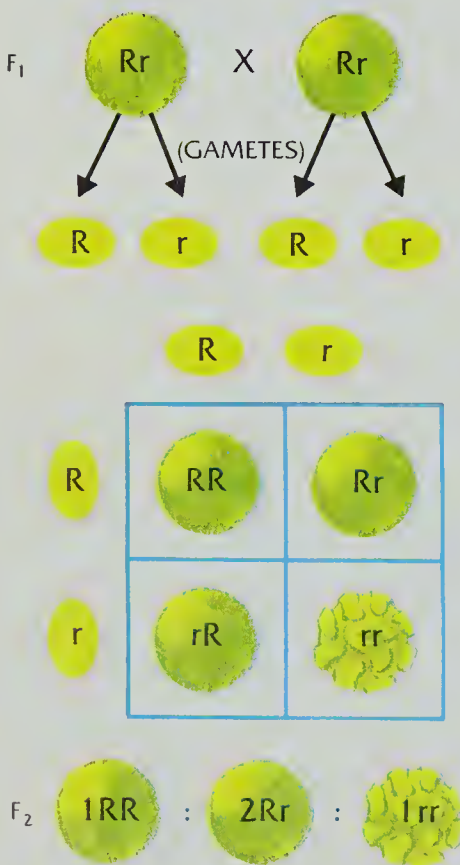
recessive

second filial generation (F_2)

probability

FIGURE 8-5

If the F_1 generation is allowed to self-fertilize, a 3 to 1 ratio of dominant to recessive traits will appear in the F_2 .



$\frac{1}{4}$ probability the F_1 seeds will be **Rr (round seeds)**

$\frac{1}{4}$ probability the F_1 seeds will be **Rr (round seeds)**

$\frac{1}{4}$ probability the F_1 seeds will be **Rr (round seeds)**

$\frac{1}{4}$ probability the F_1 seeds will be **Rr (round seeds)**

It is obvious that there are four possible combinations of factors but that they all result in the same combination. Since the probability for each occurrence is the same, the fractions can be added. The result, $\frac{4}{4}$, or 1, says that all offspring will be **Rr**. Since **R** is dominant over **r**, all plants of the F_1 generation should produce *round* seeds. None should produce *wrinkled* seeds. That is how Mendel explained the results he obtained in his F_1 generation.

8-9 Explaining Mendel's F_2 generation

Mendel still had to explain the 3:1 ratio that he obtained in his F_2 generation. Here is how that was explained. First we must diagram the cross:

$Rr \times Rr$

Each male gamete can carry either an **R** factor or an **r** factor. Likewise each female gamete can carry either an **R** or an **r**. Thus the probabilities during fertilization are:

$\frac{1}{4}$ probability the F_2 generation will be **RR (round seeds)**

$\frac{1}{4}$ probability the F_2 generation will be **Rr (round seeds)**

$\frac{1}{4}$ probability the F_2 generation will be **rR (round seeds)**

$\frac{1}{4}$ probability the F_2 generation will be **rr (wrinkled seeds)**

See Figure 8-5 for a diagram of this cross. It is assumed that **$Rr = rR$** ; the dominant factor is always written first. Thus the probabilities for **Rr** and **rR** are the same and we can add $\frac{1}{4} + \frac{1}{4}$ to obtain a $\frac{1}{2}$ probability that the F_2 generation will be **Rr** (round seeds).

In the cross between **Rr** and **Rr** there are three possible combinations that can result in the F_2 generation: **RR**, **Rr**, and **rr**. The **RR** and **Rr** will look the same; both will have *round* seeds. Thus there is a $\frac{3}{4}$ probability ($\frac{1}{4} + \frac{1}{2}$) that the F_2 seeds will be *round* and a $\frac{1}{4}$ probability that they will be *wrinkled*. Three-fourths probability means that three out of every four are likely to be *round* seeds. One out of every four is likely to be a *wrinkled* seed. This is a 3:1 ratio, which is how Mendel's F_2 generation turned out.

CHECK YOUR FACTS

1. How do genes determine much of the structure of an organism?
2. With what is the science of genetics concerned? Who founded this science?
3. Why did Mendel choose the garden pea for his research?
4. On what basis were the parent plants chosen for Mendel's crossbreeding experiments? What was surprising about the first filial generation?
5. Why did Mendel call the trait for wrinkled seeds a recessive trait?
6. What were the results of Mendel's F_1 cross?
7. What is probability? What does a probability of $\frac{1}{2}$ mean?
8. Using probability determine the nature of the F_1 generation of the following cross: **TT** (tall plants) $\times$ **tt** (short plants).
9. If the F_1 generation above fertilized themselves, what results would you expect? Diagram the cross and give the probability for each combination of genes.
10. The trait for yellow peas is dominant over the trait for green peas. If two plants that produce yellow peas were crossbred, how would you determine whether or not these plants were true-breeding for this trait?
11. How long would it take to gather the evidence needed in the question above?

More Experiments

8–10 More terms Mendel performed more breeding experiments with garden peas. But to discuss them we shall introduce some modern terms that Mendel never heard of. Today we know that Mendel's "factors," which are contributed by each parent, are genes. Two or more related genes, which control a trait such as *round* or *wrinkled* peas, are called **alleles** (ə lēlz'). The two alleles for *round* peas are symbolized **RR** or **Rr**, while the alleles for *wrinkled* peas are **rr**.

The actual alleles possessed by an individual are called the individual's **genotype** (jen'ə tīp). The genotype of a *round* pea would be **RR** or **Rr**. The genotype of a *wrinkled* pea would be **rr**.

The actual appearance of an individual, or the physical result of having a certain pair of alleles, is called the **phenotype** (fē'nə tīp). *Round* is a phenotype. *Wrinkled*, *yellow*, and *green* are other phenotypes.

ANSWERS TO CHECK YOUR FACTS

1. They determine the structure of the proteins of the organism.
2. The study of genes and how they interact in the development of new organisms. Gregor Mendel.
3. They were available in many varieties and they were self-pollinating.
4. The plants to be crossbred had contrasting traits that could not appear at the same time. Mendel was surprised when only one of the two parental traits appeared in the offspring.
5. Because it did not appear in the F_1 generation of his crossbreeding experiments.
6. One fourth of the offspring showed the recessive trait.
7. The branch of statistical arithmetic that tries to predict the results of chance events. That one result is expected from two possible results.
8. All the offspring will be **Tt** and will be tall plants.
9. $\frac{1}{4}$, $\frac{1}{2}$ **Tt**, and $\frac{1}{4}$ **tt**. $\frac{3}{4}$ of the F_2 plants would be tall and $\frac{1}{4}$ of the F_2 plants would be short.
10. If green peas appear in the generations after the F_1 generation, the original parents could not have been true-breeding.
11. Two growing seasons.

MAIN IDEA

Related genes are called alleles. Genotype refers to the alleles possessed by an organism, while phenotype refers to the physical result of the alleles.

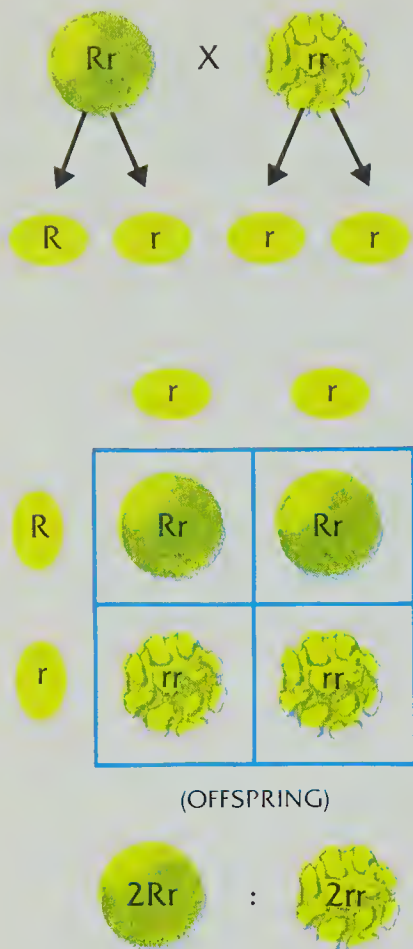


FIGURE 8–6

In the testcross the F_1 generation is crossed with the true-breeding recessive parent. A 1 to 1 ratio of dominant to recessive traits appears.

MAIN IDEA (8–11)

Mendel checked his theories by crossing Rr plants with rr plants. His predictions of a 1:1 ratio were realized in what is now known as a testcross.

MAIN IDEA (8–12)

Homozygous individuals have identical alleles; heterozygous individuals do not. Mendel raised dihybrid strains for other experiments.

8–11 The testcross Mendel's explanations for his experimental results, called hypotheses, needed to be tested in some way. For this purpose he designed a breeding experiment that has since become known as the **testcross**, or **backcross**.

Mendel believed that the *round* seeds from his F_1 generation had the genotype Rr . He decided to cross these with true-breeding *wrinkled* seeds, which he believed to have the genotype rr . The cross can be diagramed this way:

$$Rr \times rr$$

Mendel predicted the probable genotypes as follows:

- $\frac{1}{4}$ probability of genotype Rr
- $\frac{1}{4}$ probability of genotype Rr
- $\frac{1}{4}$ probability of genotype rr
- $\frac{1}{4}$ probability of genotype rr

By adding the probabilities for the four genotypes, we obtain a probability of $\frac{1}{2}$ that the phenotype of the offspring will be *round* seeds. Also there would be a $\frac{1}{2}$ probability of *wrinkled* seeds. In other words, the *round* and *wrinkled* phenotypes should be about half and half when the seeds from such a testcross are counted. The results of Mendel's testcross were 106 *round* peas and 101 *wrinkled* peas. These results greatly strengthened his hypotheses.

8–12 Producing dihybrids In other breeding experiments, Mendel produced varieties of garden peas that combined two traits. For example, he produced true-breeding varieties with phenotypes that were *round-yellow* and *wrinkled-green*. The genotypes for such varieties are written $RRYY$ and $rryy$. Because the varieties breed true and the alleles are the same, each variety is said to be **homozygous** (hō mǝ zī'gās).

Next, Mendel crossed *round-yellow* peas with the *wrinkled-green* peas ($RRYY \times rryy$). A diagram of the cross and the results are pictured in Figure 8–7. Note that all the genotypes of the F_1 generation of that cross are $RrYy$ and have alleles that are unlike. Such a genotype is said to be **heterozygous** (het ər ə zī'gās). Individuals that are heterozygous for any trait are **hybrid** (hī'brid). Also, individuals may be heterozygous for two traits. Such individuals are **dihybrid** (dī hī'brid). The phenotype of all the dihybrids is *round-yellow*.

8–13 The dihybrid cross Mendel then let his F_1 dihybrids fertilize themselves in what is now called a dihybrid cross. But before we can establish the probabilities for the genotype and phenotype of the offspring, a question

has to be answered. Are the different alleles always linked together in the gametes or are they distributed independently? In other words, does the **R** allele always go where the **Y** allele goes, or can a gamete contain an **Ry** combination? Mendel discovered that the alleles he was experimenting with were distributed independently. You can see in Figure 8–8 the four possible genotypes that might be found in each gamete: **RR**, **Ry**, **rY**, and **ry**.

To determine the probability for the different genotypes and phenotypes of the dihybrid cross, it is useful to diagram the cross using a **Punnett** (pun'it) **square**. See Figure 8–8. By matching the possible male and female gametes, there are 16 possibilities. When we examine the possible genotypes, we then see that there are probabilities for four different phenotypes. There is a 0.56 probability that the seeds will be *round* and *yellow*. There is a 0.18 probability that the seeds will be either *wrinkled* and *yellow* or *round* and *green*. Finally, there is a 0.06 probability that the seeds will be *wrinkled* and *green*. In other words, the ratio between the different phenotypes should be **9:3:3:1**.

FIGURE 8–8 Inbreeding the dihybrid F_1 will give four different phenotypes.

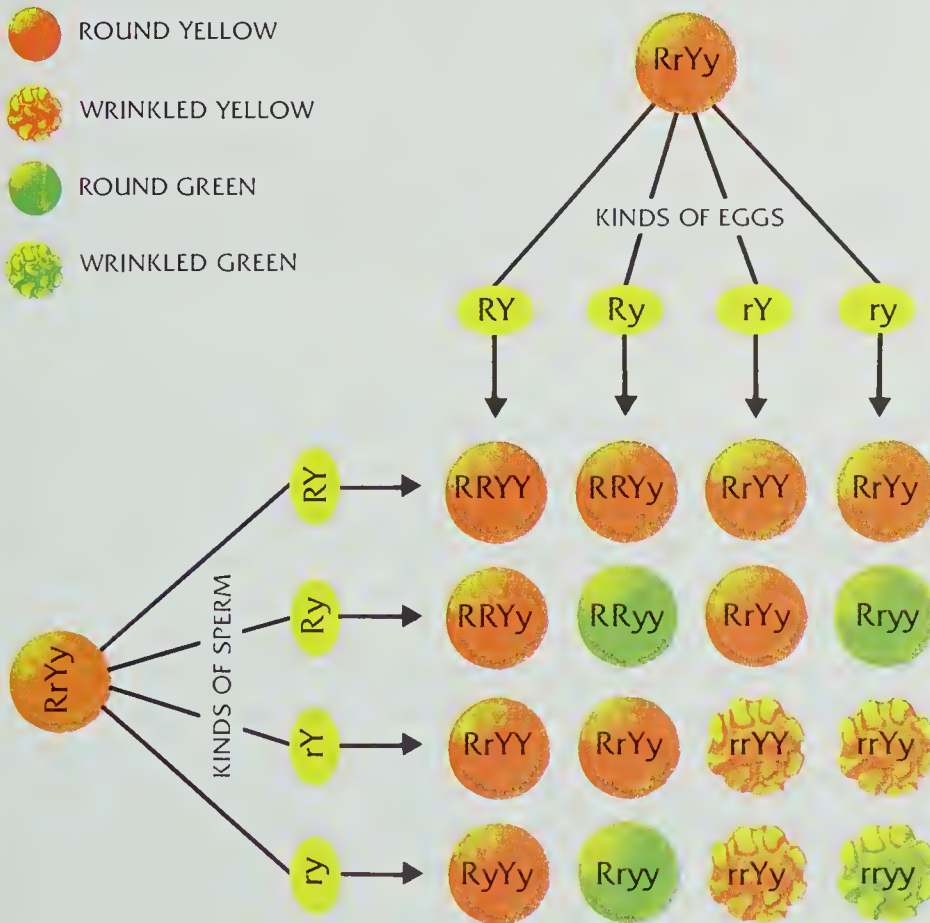
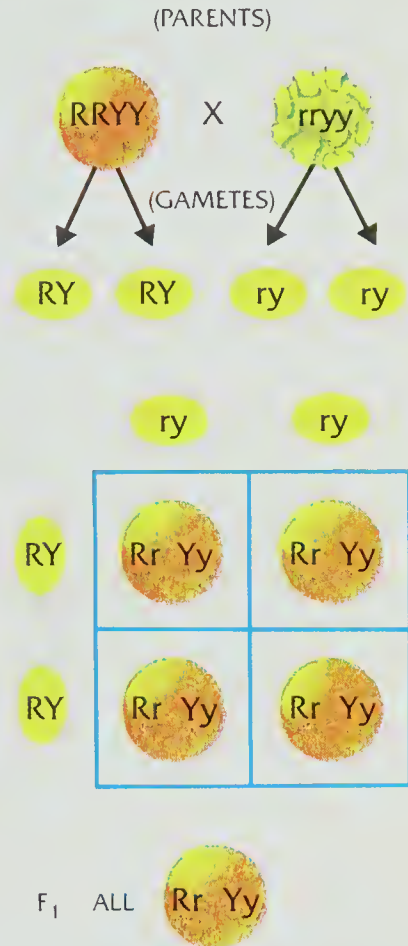


FIGURE 8–7

If an individual that is homozygous dominant for two traits is crossed with an individual that is homozygous recessive for two traits, dihybrid offspring occur.



MAIN IDEA (8–13)

In his dihybrid cross Mendel determined that the alleles are distributed independently. The Punnett square helps explain the 9:3:3:1 results that Mendel predicted and found.

What results did Mendel obtain from his dihybrid cross? Table 8–1 shows the probable and actual numbers of different peas that he obtained from his total of 556 peas in the dihybrid cross.

Table 8–1 Probable and Actual Phenotypes from Mendel’s Dihybrid Cross

<i>PHENOTYPE</i>	<i>Probable</i>	<i>Actual</i>
Round Yellow	312.75	315
Wrinkled Yellow	104.25	101
Round Green	104.25	108
Wrinkled Green	34.75	32
Total Peas	556.00	556

SCIENCE BACKGROUND

Historians speculate that Mendel’s work was not understood at the time it was presented and published because biologists at that time were not used to statistical analysis and were confused by his data.

MAIN IDEA

Mendel’s work was not recognized until 35 years after his experiments and 16 years after his death.

SCIENCE TERMS

alleles
genotype
phenotype
testcross
homozygous
heterozygous
dihybrid
Punnett square

Mendel’s results were very close to his predicted 9:3:3:1 ratio. He felt sure that he had made important discoveries about how traits are inherited. He continued his experiments, using many other varieties of garden peas, and eventually published a paper that described his discoveries.

8–14 An unknowing father Mendel began his experiments in 1857, and eight years later, in 1865, he presented his results. His presentation was made to a scientific society in the small town where he lived. It was printed in the society’s journal and was distributed to many libraries in Europe. However, his paper was either not read or not appreciated. Mendel continued experiments with other plants and bees, but he then became more involved in the work of running the monastery where he lived. His experiments suffered from neglect, and he eventually had to abandon them. He died in 1884 without any other scientists in the world knowing of his discoveries.

It was not until 1900 that his paper was “discovered.” At that time, three different biologists in Europe read his paper. All three of them realized the importance of Mendel’s work, and they spread the word of his discoveries. Soon many others had repeated Mendel’s experiments, and he was rightly credited for being the father of the science of genetics.

CHECK YOUR FACTS

1. What are alleles?
2. Distinguish between *genotype* and *phenotype*. Must organisms with the same phenotype have the same genotype?
3. Predict the outcome of the cross **Aa** × **aa**. What is such a cross called?
4. A tall plant that is *thought* to have the genotype **Tt** is crossed with a short plant, **tt**. Explain these possible results: **(a)** half the plants are short; **(b)** all the plants are tall; **(c)** only five offspring survive—four are tall and one is short.
5. A *round-yellow* pea has the genotype **RrYY**. For which trait is this plant homozygous? What phenotypes will be seen in the F₁ should this plant reproduce?
6. What is a dihybrid? What are the possible genotypes of the gametes of a **DdAa** dihybrid?
7. Dihybrid peas that are tall and have yellow seeds, **TtYy**, are crossed. What is the probability of having *tall-green* offspring? *Short-green*? Of having offspring that are homozygous for the *yellow* trait?
8. In the above cross how many of the plants would you predict to be tall? What fraction should be dihybrid? What fraction of the short plants produce yellow seeds?
9. A *tall-yellow* plant reproduces. What was its genotype if in the 160 offspring **(a)** 88 are *tall-yellow*? **(b)** 160 are *tall-yellow*? **(c)** 121 are *tall-yellow* and 39 are *short-yellow*?
10. What impact did Mendel's work have on the scientific community when he released his findings?

ANSWERS TO CHECK YOUR FACTS

1. Related genes that control a trait.
2. Genotype refers to the actual alleles possessed; phenotype refers to the physical results of the alleles. No.
3. Half the offspring would have **Aa** and show the dominant phenotype. Half would be **aa** and show the recessive trait. A testcross or backcross.
4. **(a)** The tall parent did have **Tt** genotype. **(b)** The tall parent had a **TT** genotype and the offspring all have **Tt** genotypes. **(c)** The sample was too small to be accurately predicted, but the presence of the short plant indicates that the tall parent must have had a **Tt** genotype.
5. For the *yellow* pea trait. Offspring could be *round* or *wrinkled*, but all would be *yellow*.
6. An individual that is heterozygous for two traits. **DA**, **Da**, **dA**, and **da**
7. $\frac{3}{16}$, $\frac{1}{16}$, $\frac{4}{16}$, or $\frac{1}{4}$.
8. **(a)** $\frac{12}{16}$, or $\frac{3}{4}$, of the plants. **(b)** $\frac{4}{16}$, or $\frac{1}{4}$. **(c)** $\frac{3}{4}$.
9. **(a)** **TtYy**. **(b)** **TTYy**. **(c)** **TtYY**.
10. None. His work was not "discovered" until 1900—35 years later.

Other Genetic Discoveries

8–15 Genes and chromosomes After the discovery of Mendel's work, many scientists in Europe and America began to repeat his experiments with other organisms. In most cases Mendel's results were duplicated. But some breeding experiments produced unpredicted results. Questions were raised and the experimenters began to look for answers inside the cell. Their research centered upon one specific structure: the chromosome.

In the late 1800s, after Mendel's death, the processes of mitosis and meiosis were described. The equal distribution of chromosomes to daughter cells during mitosis suggested that they contained something of equal value. Thus the

MAIN IDEA

By the early twentieth century, scientists had established that genes were carried on the chromosomes and that gametes contained one complete set of genes from one parent.

MAIN IDEA

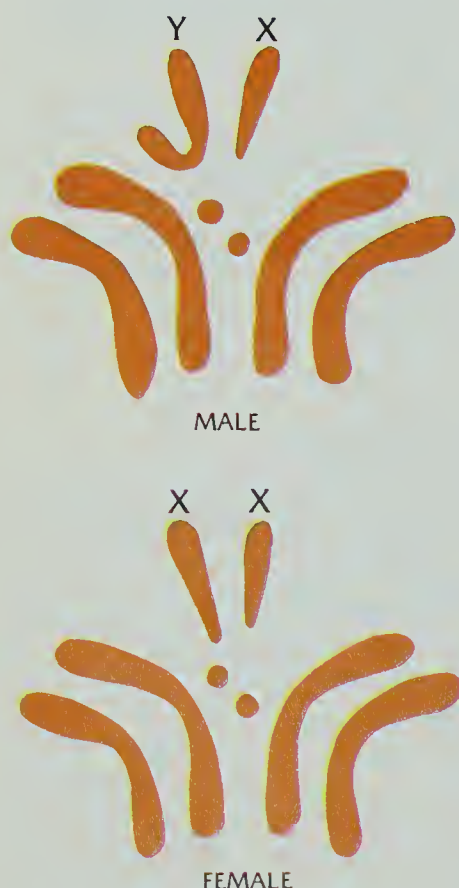
Morgan introduced the use of the fruit fly in genetic experiments. Their rapid rate of reproduction and ease of care made them superior organisms for study.

MAIN IDEA (8-17)

Unequal X and Y chromosomes, or sex chromosomes, explain why traits are sometimes sex-linked. Genes on the X chromosome are expressed as dominant genes in the male.

FIGURE 8-9

In the fruit fly, males have one X and one Y chromosome. Females have two X chromosomes.



chromosomes were a logical place for the genes to be carried. By the early twentieth century, the **chromosome** (krō'mə sōm) **theory** had been established and supported with good experimental evidence. The chromosome theory said that all genes are carried on chromosomes and that genes are distributed equally during mitosis. Also, during meiosis, each gamete is provided with one set of chromosomes containing one complete set of genes from one parent.

8-16 The fruit fly In 1910 Thomas Hunt Morgan, an American biologist, found an ideal new organism for genetic research. This was the fruit fly, *Drosophila melanogaster*, which is a small red-eyed fly that produces a new adult generation about every two weeks. The fruit flies proved easy to grow in bottles in the laboratory. Also the experimenters could study the results of about 30 generations per year. This was a vast improvement over the garden pea and most other plants, which were limited to one generation per year.

8-17 Sex-linked genes Morgan made one of his first important discoveries after crossing a normal red-eyed fly with a rare white-eyed fly that he found in one of his bottles. The white-eyed fly was a male, and he bred it with a female that had red eyes. The offspring in the F₁ generation were all red-eyed, which suggested that the trait for red eyes was dominant.

Morgan then let the F₁ generation interbreed. His results were as follows:

Red-eyed females	2 459
White-eyed females	0
Red-eyed males	1 011
White-eyed males	782

Morgan's first reaction was to ask the question, Why were no white-eyed females produced? He went to the chromosomes of the fruit fly to find the answer. The fruit fly has only four pairs of chromosomes. One pair, called the **sex chromosomes**, is unlike. One of the sex chromosomes, called an **X chromosome**, is straight. The other has a hook on one end and is called a **Y chromosome**. Females have two X chromosomes (XX), while males have one of each (XY). The same pair of sex chromosomes is found in humans and most other animals, and their presence determines the sex of the individual.

Eventually Morgan predicted why there were no white-eyed females in his F₁ generation. His hypothesis was two-



The photograph at left shows a red-eyed female fruit fly. At right is a white-eyed male. Eye color is sex-linked in fruit flies.

fold: (1) that the gene for white eyes is recessive, and (2) that the gene for eye color is carried only on the X chromosome. Below is a cross that diagrams this hypothesis, with X and Y representing the chromosomes, **R** the gene for red eyes, and **r** the gene for white eyes.

White-eyed male Red-eyed female
 X^rY $\times$ X^RX^R

There are two possible results in the F_1 generation of Morgan's first cross:

$\frac{1}{2}$ probability X^RX^r —red-eyed female
 $\frac{1}{2}$ probability X^RY —red-eyed male

The F_1 results were what Morgan obtained—all flies were red-eyed.

Morgan's second cross, where the F_1 flies were allowed to interbreed, is diagramed as follows:

Red-eyed F_1 male Red-eyed F_1 female
 X^RY $\times$ X^RX^r

In the above cross there are four possible genotypes:

$\frac{1}{4}$ probability X^rY —white-eyed X^rY
 $\frac{1}{4}$ probability X^RY —red-eyed male
 $\frac{1}{4}$ probability X^RX^R —red-eyed female
 $\frac{1}{4}$ probability X^RX^r —red-eyed female

SCIENCE BACKGROUND

At the time Morgan began his work, he was at Columbia University and was an embryologist openly hostile to Mendel's ideas. Interestingly Morgan's laboratory soon became the outstanding genetics research laboratory in the world, and geneticists Alfred Sturtevant, Calvin Bridges, and Hermann Muller were to get their start there as students.

SCIENCE BACKGROUND

Exceptions to the pattern of XX female–XY male in the animal world include butterflies, birds, amphibians, and some fishes. In these, the opposite pattern occurs: XX is the male and XY is the female.

The results show that only white-eyed males and no white-eyed females could result from such a cross. Later experiments by Morgan and his assistants proved beyond doubt that his hypothesis was correct. The gene for eye color in the fruit fly is carried on the X chromosome and not on the Y chromosome. (Very few genes are carried on the Y chromosome.) Any gene on the X chromosome of the male becomes a dominant gene. Such genes have since been named **sex-linked genes**. Several important sex-linked genes have been discovered in humans. They will be discussed in the next chapter.

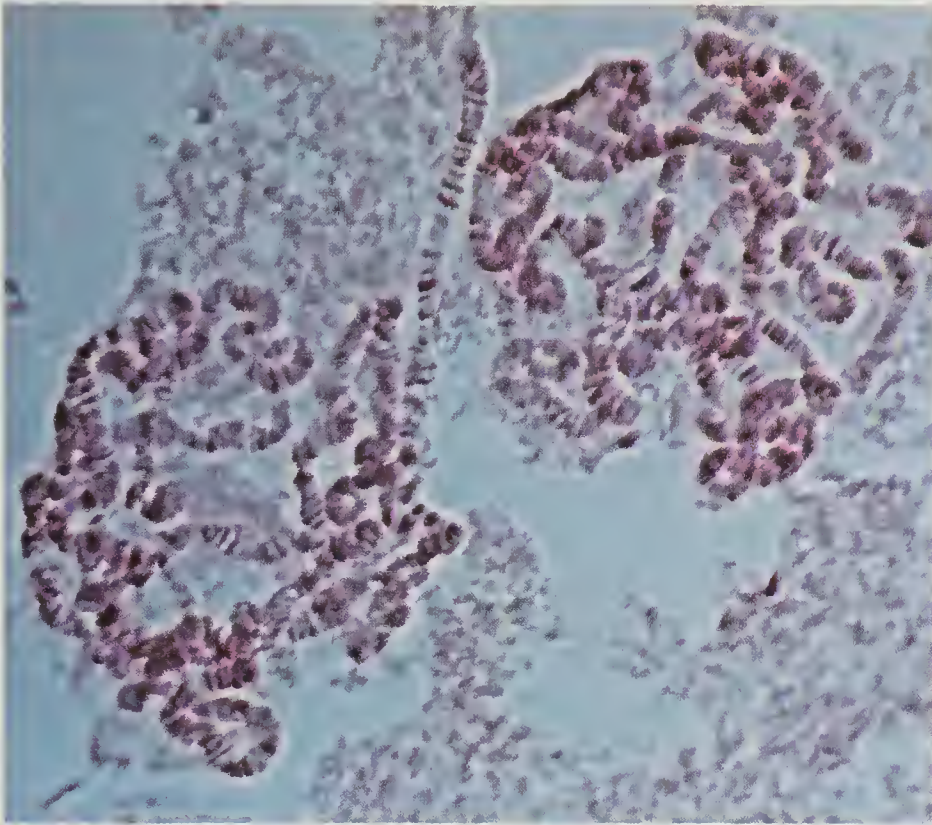
MAIN IDEA

Morgan showed that chromosomes assort independently, that genes are exchanged during the crossover of meiosis, and that chromosome maps could be constructed by studying crossover results. Giant chromosomes with bands also aided in chromosome mapping.

8–18 Linkage and crossing-over Mendel's original hypothesis was that all genes assorted independently from parents to offspring. The discovery of sex-linkage showed that this was not always true. Morgan and his group discovered that what really assorts independently are the chromosomes. They showed that genes on the X chromosome go where the X chromosome goes. Later they proved that genes on chromosomes other than the sex chromosomes, called **autosomes** (ô'tə sōmz), are also linked.

Morgan's group found exceptions to the idea of linkage. They found that some genes that are linked to a certain chromosome sometimes assort independently. Morgan explained this confusing behavior after reading the work of another biologist who had been studying the behavior of chromosomes during meiosis. During meiosis, gametes, which have one set of chromosomes, are formed. During the first phase of meiosis the replicated chromosomes, called chromatids, come together in a tetrad side-by-side arrangement. Often there is an exchange of material between two adjacent chromatids, which is called **crossing-over**. Morgan saw that the crossing-over could cause an exchange of genes. This could explain why genes do not always remain linked to one chromosome, but sometimes assort independently. With careful experiments, Morgan demonstrated that this does happen. Further, Morgan and his associates conducted enough experiments to be able to predict the frequency of crossover for most fruit fly genes. By using this information, they were able to construct actual chromosome maps. Their maps showed that the genes are arranged along the chromosome like beads on a string.

It is an interesting coincidence that certain cells in the fruit fly, which are in the salivary glands, have chromosomes far larger than others in the body. These **giant chromosomes** were found to have bands that corre-



In the above photograph of giant chromosomes from the salivary glands of a fruit fly, the bands corresponding to the location of genes can be seen.

sponded to the location of certain genes. Thus, for years after Morgan's first work at chromosome mapping, other geneticists were able to develop accurate maps using the giant chromosomes. It is important to remember that all this research was done before the discovery of DNA and the true nature of genes. Now we know why genes are like beads on a string. Genes are sequences of nucleotides in a huge, long string of DNA that is coiled inside the chromosomes.

8-19 Incomplete dominance Other geneticists who were testing Mendel's ideas sometimes ran into difficulty with his idea of dominance. For example, when crossing certain flowers, such as the Japanese four-o'clock, a different pattern resulted. When red four-o'clocks were crossed with white four-o'clocks, the F_1 seeds did not produce red or white flowers. Instead all the flowers were pink, which was a blend of the two traits. This indicated that neither gene in the heterozygote was dominant over the other. Such results produced a new term to describe alleles that are equally dominant. This new term was **incomplete dominance** (dom'ə nəns).

SCIENCE BACKGROUND

As new knowledge of molecular genetics and gene action is acquired, the old concept of dominance is gradually being outmoded. When tests for enzyme quantity and function are available, it is usually possible to detect a heterozygote. Therefore, the modern view is that dominance, with some exceptions, should be considered as incomplete dominance.

MAIN IDEA

Incomplete dominance was found to produce a unique phenotype in heterozygous individuals.

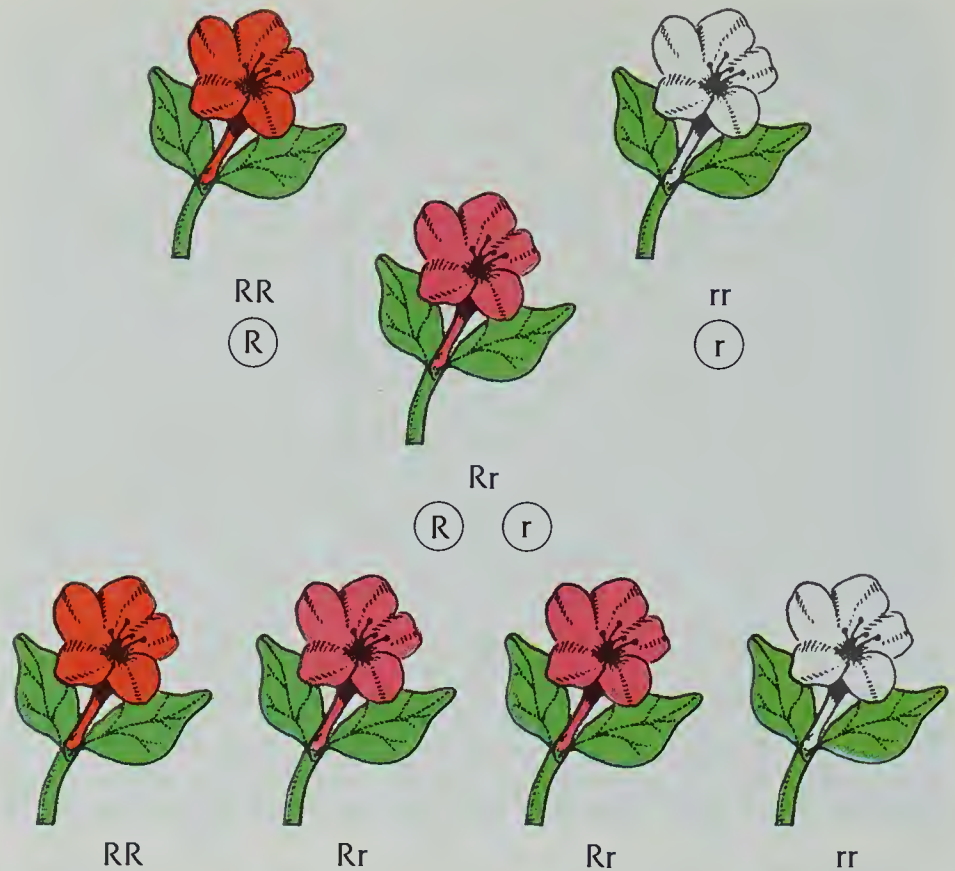


FIGURE 8–10 In Japanese four-o'clock plants there is incomplete dominance with respect to flower color.

A further result of incomplete dominance can be seen when the F_1 generation is allowed to interbreed. The crossing of two heterozygotes (**R = red, r = white**) is diagramed as follows:

pink F_1 four-o'clock pink F_1 four-o'clock
Rr x Rr
 $\frac{1}{4}$ probability RR—red four-o'clock
 $\frac{1}{2}$ probability Rr —pink four-o'clock
 $\frac{1}{4}$ probability rr —white four-o'clock
results in all three phenotypes—red, pink, and white.

MAIN IDEA

Codominance results in the presence of both phenotypes.

SCIENCE BACKGROUND

Sickle-cell anemia is an example of a phenotype that results from codominant alleles. This will be discussed in Chapter 9.

8–20 Codominance Another gene relationship is called **codominance**, where both alleles are expressed in an individual. Codominance occurs in Shorthorn cattle when there are crosses between animals with red and white coats. The offspring have a coat that is reddish gray, called roan. This would appear to be a case of incomplete dominance until the hair is examined. The coat is made up of a mixture of red and white hair, not hair of an intermediate color. Other examples of codominance that relate to humans will be discussed in the next chapter.

8-21 Multiple alleles The normal rabbit has a coat of hair that is multicolored and is called **agouti** (ə gū'tē). The hair nearest the skin is gray, followed by a yellow band, with the tip of the hair colored black or brown. But there are rabbits with coats of other colors. The albino rabbit is without pigment in its hair or eyes. Its hair is white and its eyes are pink. Another variety, called chinchilla, lacks the yellow band in the hair and appears silvery gray. A fourth type, called Himalayan, is white except for black on the nose and the tips of the ears, feet, and tail. Breeding experiments with these four different varieties show that there may be more than two alleles for a trait. Such alleles are called **multiple alleles**.

When normal, or agouti-colored, rabbits are bred with albino rabbits, the result is an agouti-colored rabbit. Clearly, the agouti allele is dominant over the albino allele. When the F_1 individuals interbreed, the result is as predicted: **$\frac{3}{4}$ of the individuals are agouti; $\frac{1}{4}$ are albino.**

The same pattern results when agouti rabbits are crossed with either the chinchilla or Himalayan variety. This indicates that agouti is dominant over the other alleles. When

SCIENCE TERMS

chromosome theory
sex chromosomes
sex-linked genes
autosomes
crossing-over
giant chromosomes
incomplete dominance
codominance
multiple alleles

MAIN IDEA

Some traits are determined by multiple alleles. These can result in a variety of phenotypes.

SCIENCE BACKGROUND

The ABO blood group is another example of multiple alleles. The pattern of inheritance of these alleles will be discussed in Chapter 9.

FIGURE 8-11 There are four different varieties of hair-coat color in rabbits. Multiple alleles are involved in this situation.



ANSWERS TO CHECK YOUR FACTS

1. That genes are carried on the chromosomes; that genes are distributed equally in mitosis; and that gametes contain one complete set of chromosomes with one complete set of genes from one parent.
2. It is easy to grow them and they reproduce rapidly. Also it has giant chromosomes that are useful in gene mapping.
3. A pair of unlike chromosomes that determine the sex of the organism. Yes.
4. About $\frac{1}{4}$ of all males and females would have had white eyes.
5. Because the Y chromosome in the male cannot carry a dominant allele to negate a recessive allele on the X chromosome. Females have two chances of having a dominant allele because they have two X chromosomes.
6. Those chromosomes that are not sex chromosomes.
7. By crossing-over during meiosis.
8. Studying the frequency with which certain genes cross over during meiosis.
9. A phenotype that shows the influence of both alleles.
10. In codominance both alleles are fully expressed and neither dominates; a mixture of the two results. In incomplete dominance there is a blend of the two alleles, resulting in an intermediate trait.
11. One allele must be for the Himalayan trait. The other allele could be that for albino or for Himalayan.

chinchilla and albino are crossed, all the offspring are chinchilla. Interbreeding the F_1 generation results in $\frac{3}{4}$ **chinchilla offspring** and $\frac{1}{4}$ **albino**. This shows two things: (1) There are alleles for both the chinchilla trait and the albino trait. (2) The chinchilla trait is dominant over the albino trait.

Other experiments have shown that a Himalayan-albino cross results in all Himalayan-colored rabbits and that a chinchilla-Himalayan cross results in all chinchilla-colored rabbits. Therefore there are at least four different alleles for rabbit coat color. Also, among the alleles there is an order of dominance: agouti is dominant over chinchilla; chinchilla is dominant over Himalayan; and Himalayan is dominant over albino.

CHECK YOUR FACTS

1. What three things does the chromosome theory propose?
2. Why is the fruit fly an ideal organism for genetic research?
3. What are sex chromosomes? Is the Y chromosome found in males only?
4. Had the recessive gene for white eyes not been sex-linked, how would the outcome of Morgan's experiment have differed from the actual results?
5. Why are sex-linked genes more apparent in males than in females?
6. What are autosomes?
7. How can genes sometimes assort independently from the chromosome to which they are linked?
8. What method was used to construct chromosome maps?
9. What phenotype is associated with incomplete dominance?
10. How is codominance different from incomplete dominance?
11. What alleles might a Himalayan-colored rabbit possess?

SUMMARY

Genetics is the study of genes and the role they play in the development of new organisms. Modern genetics was founded by Gregor Mendel, a monk who experimented with pea plants in the middle 1800s. Mendel crossbred true-breeding varieties that showed contrasting traits. The trait he was to label *recessive* vanished in the first generation, only to reappear in $\frac{1}{4}$ of the second generation plants. Using his knowledge of proba-

bility, Mendel reasoned that each parent contributes one factor and that a recessive trait appears only when a dominant factor is not present.

The chromosome theory states that *genes are carried on chromosomes, that genes are equally distributed in mitosis, and that gametes contain a complete set of genes from one parent*. Thomas Morgan proposed that chromosomes assort independently and that genes are exchanged during cross-over that occurs in meiosis.

REVIEW QUESTIONS

1. If half the offspring are homozygous recessive and the other half are heterozygous, what alleles did the parents possess in this crossbreeding?
2. Are all organisms with a recessive trait true-breeding for that trait?

Questions 3–5 refer to offspring of the following cross: **SsAa × SsAa**. *S* stands for long stems, *s* is the recessive allele for short stems, *A* is for axial flowers (flowers near the stem), *a* is the recessive allele for terminal flowers.

3. What fraction of the offspring should have long stems? Axial flowers?
4. How many show no recessive phenotypes? No dominant phenotypes?
5. What fraction of the offspring should breed true? What is the most frequently occurring genotype? Phenotype?
6. In the cross **TtYy × TtYY** give the ratio of the phenotypes you would expect. (**T** is tall, **Y** is yellow seeds.)
7. In the cross **TtYy × TtYY** what are the possible genotypes that could be produced?
8. How did Morgan explain the absence of white-eyed females in his F_2 generation?
9. Do all genes assort independently? Explain.
10. True-breeding *long* radishes are crossed with true-breeding *round* radishes. The F_1 generation are all oval-shaped. How do you explain the F_1 generation? What predictions can you make for the F_2 generation?

ANALYSIS AND APPLICATION

1. How would you breed a white-eyed female fruit fly?
2. Assume that you have in your laboratory three varieties of a flower that breed true for a different color. One group is red, one is orange, and the other is yellow. You wish to find out if there are three alleles for the colors or if red and yellow alleles produce orange flowers through incomplete dominance. How would you find out?

ANSWERS TO REVIEW QUESTIONS

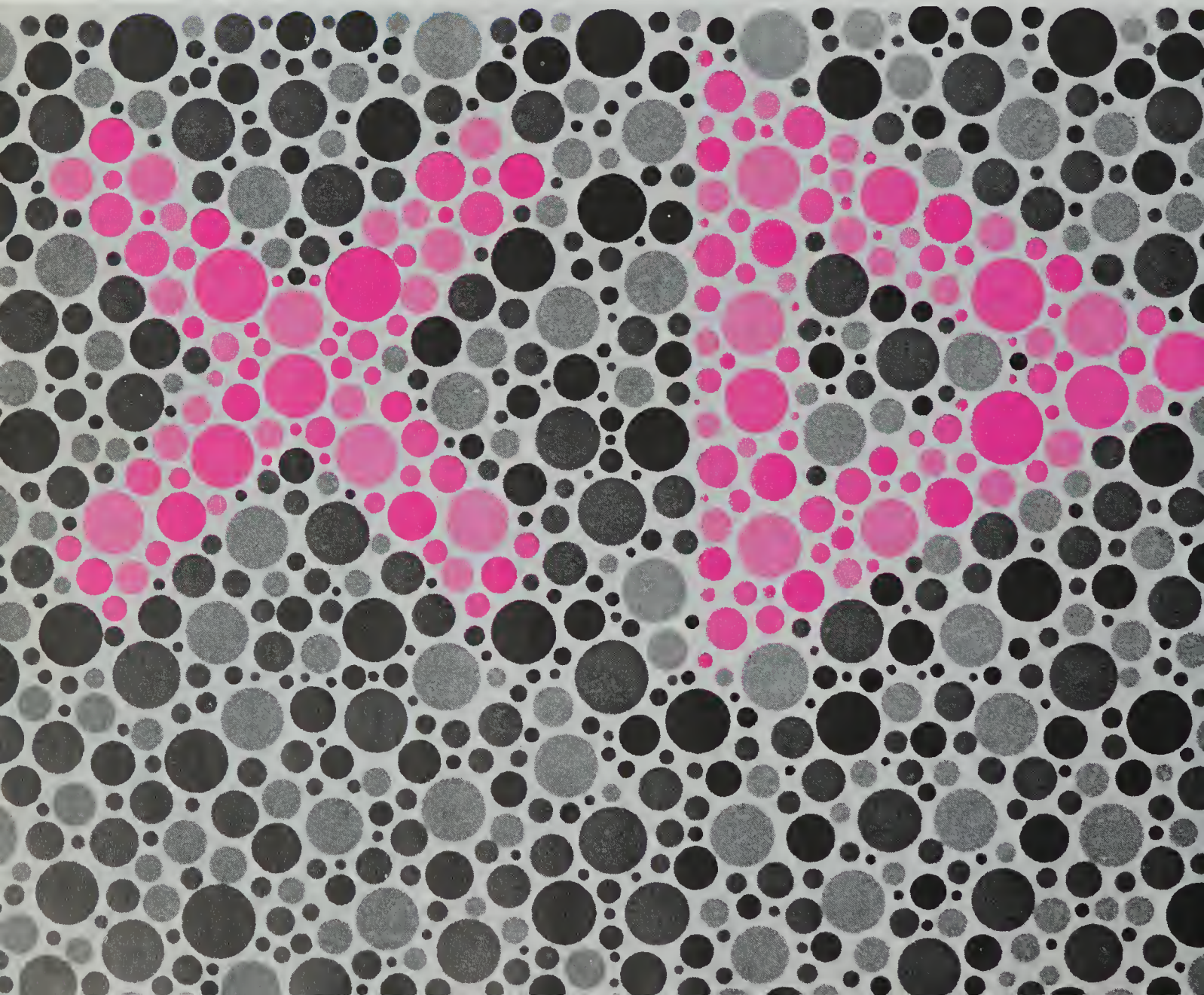
1. One was homozygous.
2. Yes.
3. $\frac{12}{16}$, or $\frac{3}{4}$. $\frac{12}{16}$, or $\frac{3}{4}$.
4. $\frac{9}{16}$, $\frac{1}{16}$.
5. $\frac{4}{16}$, or $\frac{1}{4}$ **SsAa**. Long stems and axial flowers.
6. 3 tall-yellow; 1 short-yellow.
7. **TTYy, TTYy, TtYY, TtYy, ttYY, ttYy**.
8. He reasoned that the gene for red eyes in the red-eyed male parent had to lie on the single X chromosome of the male. Since all female offspring must receive the X chromosome from the male, they also receive the dominant allele for red eyes.
9. Generally not—they are linked to the chromosome that carries them. Crossovers allow exceptions to this linkage.
10. The alleles involved exhibit incomplete dominance. The F_2 should produce $\frac{1}{4}$ long, $\frac{1}{2}$ oval, and $\frac{1}{4}$ round.

ANSWERS TO ANALYSIS AND APPLICATION

1. Breed white-eyed males with heterozygous females.
2. Cross the red variety with the yellow variety. If all the F_1 generation are orange, there are two alleles. If the F_1 generation are either all red or all yellow, multiple alleles are present.

Investigations 21–22 from *Laboratory Investigations in Biology* can be done with this chapter.

9 *Human*



OBJECTIVES

- To explain dominance–recessiveness
- To understand how discontinuous traits are inherited

- To explain the genetic basis for sickle-cell anemia
- To discuss how rare genetic diseases are inherited
- To understand the inheritance patterns and potential of ABO and Rh blood
- To explain the inheritance of sex chromosomes
- To appreciate the problems that can result when chromosome additions and deletions occur
- To explain how the factors of heredity and environment are related

Genetics

Patterns of Inheritance

9–1 Kinds of traits Mendel's experiments were designed to find out how **discontinuous** (dis kən tin'yü əs) **traits** are inherited. Discontinuous traits are traits that can be clearly observed as two or more distinct differences. Some examples are pea seeds that are round or wrinkled, and fruit flies with red or white eyes. Discontinuous traits that are inherited by the patterns discovered by Mendel are called Mendelian patterns. These were the patterns that were discussed in the last chapter.

There are about 1 000 discontinuous human traits that are inherited according to Mendelian patterns. Most of these are recessive traits that result in rare **genetic diseases**. Genetic diseases are inherited and are caused by genes, or the lack of genes. Usually most people have little interest in rare genetic diseases. What people want to know more about are such traits as tallness, eye color, skin

MAIN IDEA

Discontinuous traits are easy to define. In humans, many result in genetic disease. Continuous traits are polygenic and are harder to define.



Most human traits, such as eye color, are continuous traits. Several pairs of genes are involved in the production of continuous traits.

MAIN IDEA

Dominant genes are “good” because they usually produce normal polypeptides. Recessive genes do not produce normal polypeptides. Heterozygotes usually produce enough workable polypeptides from their dominant, or “good,” gene.

SCIENCE BACKGROUND

One genetics writer compares the homozygous dominant pair of genes and the heterozygous pair as being like a wagon drawn with two horses or a single horse. Under most conditions the single horse can pull the wagon (the single dominant gene can produce enough of a normal polypeptide), but when pulling a heavy load (stress), the single horse cannot do as good a job as the team.

We have used the terms *good* and *bad* to describe genes. Generally that is a way of distinguishing dominant and recessive genes. However, there are recessive genes that result in certain harmless human variations, such as an attached earlobe. Also, a dominant gene can be a “bad” gene, as is the case of the dominant gene that causes Huntington’s disease. This particular dominant gene produces a factor that interferes with normal brain development.

color, facial features, and intelligence. These are traits of another kind. They are **continuous** (kən tin’yū əs) **traits**, where offspring show a continuous range of characteristics that are often impossible to define with accuracy. Continuous traits are **polygenic** (pol ē jen’ik), which means that several genes are involved in producing the trait. Polygenic traits are very difficult, if not impossible, to analyze by Mendelian patterns of inheritance.

9–2 How discontinuous traits are produced In this chapter we shall discuss some discontinuous traits that are inherited by Mendelian patterns. But first we must explain how such traits are produced in the human body.

A gene is a sequence of nucleotides in a DNA molecule, which codes an amino acid sequence of a polypeptide chain. The polypeptide chain may be a protein all by itself, or it may be one of several that make up a larger protein. Many of the genes that we are concerned with in human genetics are those that code for polypeptides that make up enzymes. Enzymes are specialized proteins that control chemical reactions in the body.

One of Mendel’s discoveries was the behavior of dominant and recessive genes. Now, with our knowledge of DNA, genes, and proteins, we must take a new look at dominant and recessive genes. At the DNA, gene, and protein levels, how are dominant and recessive genes different?

As a general rule, dominant genes are “good” genes that have a code for making a normal polypeptide. This normal polypeptide is often a part of an enzyme that controls some chemical reaction in the body. A person who is homozygous for two dominant genes has a double quantity of “good” genetic information. The information of one or both genes may be used to make “good” polypeptides. But the second gene may not be needed. The cell may only use both genes when a large number of polypeptides are needed. Or, the cell may use the second “good” gene as a backup in case it is needed for some other reason.

A recessive gene is one that contains a code that (1) does not produce a polypeptide that will function; or (2) produces a polypeptide that functions improperly, or not as well as a normal gene. A recessive gene is generally a “bad” gene.

You will recall from the last chapter that many organisms are heterozygous for a trait. This means that they have one dominant gene and one recessive gene. Mendel learned that there is no visible difference between a het-

erozygote and a dominant homozygote (an organism with two dominant genes). His round peas with the genotype **RR** looked exactly like his **Rr** peas. How can this be explained in terms of DNA, genes, and proteins?

Generally a heterozygote has one “good” gene and one “bad” gene for a trait. The dominant, or “good,” gene causes normal polypeptides to be formed. There are enough of the normal polypeptides formed, so that the proper enzyme, or other protein, performs its normal function. The recessive, or “bad,” gene either does not function or functions improperly. As a result, the heterozygote often looks the same and apparently functions the same as the dominant homozygote. However, when the heterozygote is studied carefully, differences can often be observed. If the gene codes for an enzyme, or part of an enzyme, that difference can often be detected. The homozygous dominant will produce more of an enzyme, or the enzyme function will be performed more efficiently.

What happens when two recessive genes are paired? Generally, this means that there are two “bad” genes and that the right kind of polypeptide will not be produced. In humans this can cause a disease or an abnormal condition. We shall discuss several examples that will illustrate the effect of homozygous recessive genes in humans.

9-3 Albinism The pigment that colors human skin, hair, and the iris of the eye is called **melanin** (mel’ə nin). Most people have some melanin, although there is wide variation in the amount, and the trait is discontinuous. However, there is a continuous trait that is quite rare and is inherited by a Mendelian pattern. This is the trait called **albinism** (al’bə niz əm). A person with albinism, called an albino, produces no melanin but is normal in all other ways. The albino has clear skin, white hair, and pink eyes.

Melanin is produced by a series of chemical reactions that start out with the amino acid tyrosine. These chemical reactions require at least one enzyme that is not produced in the albino. If we let **A** represent the dominant gene, a person that is **AA** or **Aa** would make enough of the enzyme to convert tyrosine to melanin. A person with both recessive genes, **aa**, would not be able to produce the enzyme and would have no pigment.

How would albinism be inherited? Could a normally pigmented person marry an albino and produce normally pigmented children? The answer can be determined by diagramming a simple Mendelian cross, but first we must know one fact. Only about 1 in 50 persons is a heterozygote, or

SCIENCE TERMS

discontinuous traits
genetic diseases
continuous traits
polygenic
melanin
albinism

MAIN IDEA

Albinism is a rare discontinuous trait that prevents melanin production. An albino child can result if both parents are carriers.



The gene for albinism is recessive. A person who has two genes for albinism does not produce the pigment known as melanin.

SCIENCE BACKGROUND

A certain amount of melanin in the skin cells provides the basis for the normal pigmentation of the skin. The stimulus from ultraviolet radiation can cause more melanin to be produced, which produces the tanning effect. An albino lacks the ability to produce melanin when exposed to the sun and therefore runs the risk of being severely burned.

ANSWERS TO CHECK YOUR FACTS

1. Traits that can be clearly observed as distinct differences.
2. Traits that show a continuous range of characteristics and are not easily defined. Tallness, eye and skin color, facial features, and intelligence are examples.
3. Discontinuous traits.
4. That more than one gene is involved.
5. They control the chemical reactions in the body. Genes (DNA).
6. Because they usually code for a normal polypeptide necessary to make a normal enzyme.
7. No. Usually they produce a nonfunctioning or poorly functioning polypeptide.
8. Because their one "good" gene is usually able to make the normal polypeptide in adequate amounts.
9. The pigment that colors the skin, hair, and iris. Continuous.
10. The trait of not producing any melanin. Yes. If both are carriers there is a $\frac{1}{4}$ probability that their offspring will be albinos.

"carrier" of this recessive gene. Therefore the probability is 49 out of 50 that the cross would be as follows:

Homozygote Albino
AA **x** **aa**

Only one possible genotype can result from such a cross: **Aa**. Therefore the probability is that 49 out of 50 marriages between an albino and a normal person will produce children with normal pigmentation.

But what if an albino marries a carrier of the recessive gene and children result? Again, a simple Mendelian cross reveals the probable results:

Carrier Albino
Aa **x** **aa**

There are two possible genotypes and phenotypes:

$\frac{1}{2}$ probability **Aa**—normally pigmented

$\frac{1}{2}$ probability **aa**—albino

Could two normally pigmented persons produce an albino child? It would be unlikely but possible if two carriers were to marry. (That probability is $\frac{1}{50} \times \frac{1}{50}$, or $\frac{1}{2500}$.) For example:

Carrier Carrier
Aa **x** **Aa**

There are three possible genotypes and two possible phenotypes:

$\frac{1}{4}$ probability **AA**—normally pigmented

$\frac{1}{2}$ probability **Aa**—normally pigmented

$\frac{1}{4}$ probability **aa**—albino

CHECK YOUR FACTS

1. What are discontinuous traits?
2. What are continuous traits? Give an example.
3. Did Mendel's experiments with peas exhibit discontinuous or continuous traits?
4. What is meant by *polygenic*?
5. Why are enzymes important? What codes for their production?
6. Why are dominant genes considered "good"?
7. Do recessive genes produce normal polypeptides?
8. Why do heterozygotes function normally for the most part?
9. What is melanin? Is skin color usually a continuous or discontinuous trait?
10. What is albinism? Could two normally pigmented people produce an albino child?

Recessive Genes and Genetic Disease

9-4 Sickle-cell anemia Sickle-cell anemia is a genetic disease. It is caused by an abnormal form of hemoglobin, which is the oxygen-carrying protein molecule in red blood cells. The abnormal hemoglobin has the amino acid valine instead of glutamic acid in two of the four polypeptides in the protein. The abnormal chains are identical, so there is only one “bad” gene that is responsible.

A person with normal hemoglobin has a genotype that is written **Hb^AHb^A**. **Hb** is the symbol for hemoglobin and the superscript **A** symbolizes normal hemoglobin.

A person that is heterozygous for the sickle-cell gene is called a “carrier” or is said to “have the trait.” The genotype of such a person is written **Hb^AHb^s**, with **S** symbolizing the sickle-cell gene. In the carrier both genes produce polypeptides that end up in the hemoglobin. In any red blood cell about 65 percent of the hemoglobin is **Hb^A** and about 35 percent is **Hb^s**. Such a person does not have sickle-cell anemia. However, it is believed by some researchers that extreme conditions, such as lack of oxygen, can cause some symptoms of the disease. This possibility will be discussed later.

A person that is homozygous for the sickle-cell gene will have sickle-cell anemia. The genotype is written **Hb^sHb^s**.

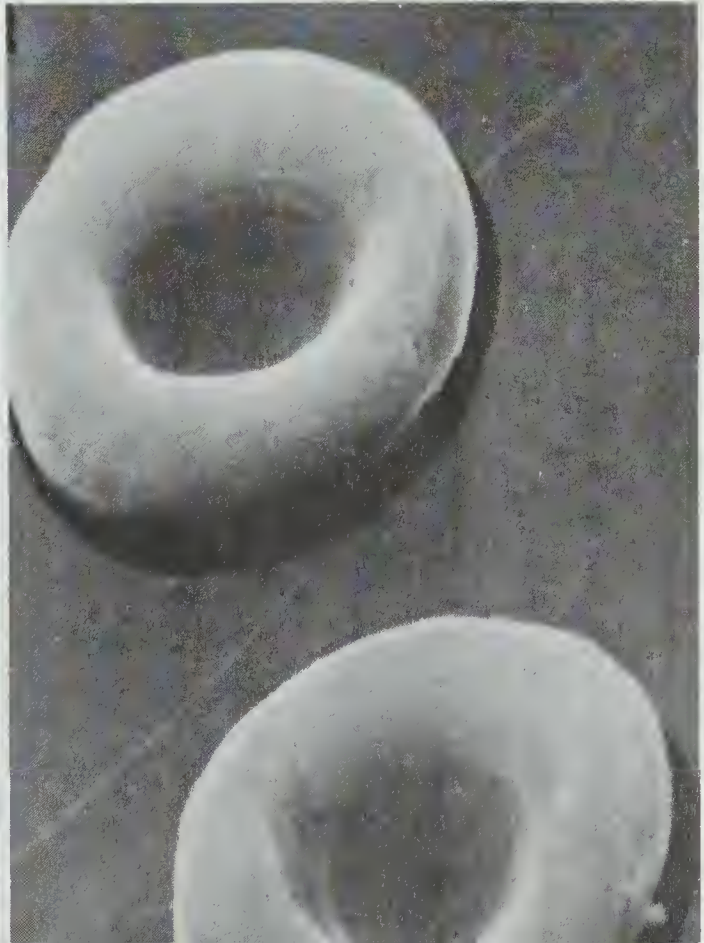
MAIN IDEA

Persons heterozygous for sickle-cell anemia do not have the disease but do have some of the abnormal hemoglobin in their erythrocytes. Those with two recessive genes have no normal hemoglobin and do have the disease.

SCIENCE BACKGROUND

Various authors describe the dual expression of Hb^A and Hb^s as intermediate dominance and codominance.

The sickle-shaped cells in the left photograph result from an abnormal form of hemoglobin. Normal red blood cells are shown on the right.



All the hemoglobin in the red blood cells of such a person is abnormal. This causes many of the cells to assume the sickle shape. Some of the sickle cells break apart and others jam up in small blood vessels. Tissues and organs that are served by the clogged blood vessels become deficient in oxygen. This causes intense pain and usually long-term damage to the tissues and organs.

At the present time, there is no successful method of treating sickle-cell anemia.

MAIN IDEA

The high carrier-rate gave Africans more resistance to malaria.

A person who has one gene for normal hemoglobin and one sickle-cell gene has a greater resistance to malaria than a person with two genes for normal hemoglobin.



9-5 A gene that is “good” and “bad” The **Hb^s** gene is most commonly found in persons of African descent. About one of every ten Americans of African descent is a carrier. But in some regions of Africa up to 35 percent of the people are carriers. When the cause of the disease was discovered, researchers wondered why a gene so harmful would be so common among the African people. Other harmful genes are never found in such a large number of people.

Researchers soon had an explanation for the abundance of the sickle-cell gene in African people. They found that most people with the **Hb^s** genes were in regions where the disease called malaria was common. Malaria is caused by a mosquito-transmitted parasite. The parasite bores into the red blood cells, multiplies, then escapes and destroys the cells. It is now generally accepted that the **Hb^s** gene helps protect African people from the malaria parasite. It is believed that babies and young children who are heterozygous (**Hb^AHb^s**) have blood cells that somehow resist the invasion of the parasites. Certainly those Africans have demonstrated a much greater resistance to malaria than Europeans with **Hb^AHb^A** hemoglobin. However, the protection has not been without a price. In Africa those who have inherited the **Hb^sHb^s** genotype have usually paid the price with pain and early death.

9-6 How is the sickle-cell trait inherited? The sickle-cell trait is inherited by a simple Mendelian pattern. First, consider a cross between a person with normal hemoglobin and a carrier:

Normal hemoglobin		Carrier (person with trait)
Hb^AHb^A	x	Hb^AHb^s
½ probability Hb^AHb^A —child with normal hemoglobin ½ probability Hb^AHb^s —child a carrier 0 probability —child with sickle-cell anemia		

As you can see, there is no chance that such a cross could produce a child with sickle-cell anemia.

What happens if two carriers have children? Again, the probability of such an event can be predicted with a simple Mendelian cross.

Carrier		Carrier
Hb^AHb^s	x	Hb^AHb^s

- ¼ probability **Hb^AHb^A**—child with normal hemoglobin
- ½ probability **Hb^AHb^s**—child a carrier
- ¼ probability **Hb^sHb^s**—child with sickle-cell anemia

There is a 1 in 4 probability that a child born to a couple who are both carriers will have sickle-cell anemia.

9–7 Problems of the carrier When the cause of sickle-cell anemia was first discovered, there was much confusion about the health of carriers. Does the approximately 35 percent S-type hemoglobin in their red blood cells create a health hazard for them? Unfortunately, there was an overreaction by some employers. For example, airline companies questioned whether a carrier should be allowed to pilot a commercial airplane or to work as a cabin attendant. It was believed that such persons might suffer a sickling of their cells if the plane were to suddenly lose its internal compression. Rigorous physical tests have since been performed on carriers. Now they are being hired as both pilots and cabin attendants by major airlines.

The chief problem of the carrier now is deciding whether to have children. As we have demonstrated, there is no problem if only one of the mates is a carrier. But if both are carriers, there is the probability that one child in four will have the disease. Fortunately today there is a blood test that will determine whether a person is a carrier of **Hb^s**. But we still have no way of knowing in advance, while a baby is developing, if it has inherited the unlucky genes. That can only be determined after the baby is born.

9–8 Other genetic diseases Imagine a new baby that has been brought home from the hospital. It is bright and alert and seems normal in every way. But then it gradually becomes dull and loses interest in things around it. Also it begins to vomit up its milk and it develops a swollen stomach. If the baby does not receive immediate attention, there is a possibility that it will become blind and develop severe brain damage. What is the problem? It could be a genetic disease call **galactosemia** (gə lak tə sē' mē ə).

Galactosemia is the result of two recessive genes. Both are “bad,” and because of them there is an important enzyme that is not produced. This is the enzyme needed to convert galactose into glucose. Galactose is one of the two

MAIN IDEA

Sickle-cell anemia is inherited by Mendelian patterns.

MAIN IDEA

Parents that are both heterozygous, or carriers, have a one-in-four chance of having a child with sickle-cell anemia. Through tests it is possible to determine if a person is a carrier.

SCIENCE BACKGROUND

There are several tests for determining the presence of Hb^s in a carrier. The most reliable is electrophoresis, which makes use of the fact that hemoglobin varieties (there are many besides Hb^s) vary in their degree of negative charge and hence their rate of movement toward the positive pole.

MAIN IDEA

Galactosemia results when the enzyme that breaks down galactose is not produced. PKU and Tay-Sachs disease also result from a missing enzyme.



A blood test can determine if a baby has phenylketonuria. If the disease is present, a special diet during childhood can prevent retardation.

simple sugars in milk sugar (lactose). After the breakdown of milk sugar, galactose is converted to glucose and used for energy. The baby with galactosemia lacks the enzyme, and the galactose builds up in the blood and acts as a poison. Fortunately there is a simple treatment. Once the disease is discovered, the baby is given a food other than milk. Galactose is rare in other foods, so without milk in the diet the baby can grow up to be a healthy, normal child.

Another genetic disease is **phenylketonuria** (fen əl kē tə nyūr'ē ə), which is abbreviated **PKU**. This disease also affects new babies and is the result of two recessive genes and the lack of an enzyme. PKU is caused by the lack of a liver enzyme that breaks down the amino acid phenylalanine. Phenylalanine is common in most proteins. While a baby with PKU is developing, the enzyme in the mother's liver breaks down the phenylalanine. But within three days after birth, the phenylalanine starts to build up in the bloodstream. Eventually such a buildup can cause improper brain development and a severe type of mental retardation. Now many states require that the blood of new babies be tested for this disease. If PKU is discovered, a special diet can be used until the child is about nine years old. After that the brain is fully developed and there is no further risk unless the person is a female and becomes pregnant. A pregnant mother must follow the special diet because any surplus phenylalanine in her bloodstream could damage the brain of her baby.

Another genetic disease, called **Tay-Sachs** (tā'saks) **disease**, is mostly found among descendants of eastern European Jews. This disease results from double recessive

SCIENCE TERMS

sickle-cell anemia
galactosemia
phenylketonuria
Tay-Sachs disease

genes and the lack of an enzyme that breaks down fatty polysaccharides, or mucopolysaccharides. A few months after birth, fatty deposits begin to accumulate around brain cells and severe brain damage results. Fortunately the disease is rare. Unfortunately there is no treatment, and most children with the disease die within a few years.

CHECK YOUR FACTS

1. What is meant by the following genotype: **Hb^AHb^S**?
2. Does a carrier of the sickle-cell gene have normal hemoglobin? Explain.
3. How does sickle-cell anemia affect the body?
4. What advantage has the **Hb^S** gene offered to **Hb^AHb^S** genotypes in Africa?
5. Two carriers wish to have children. What is the probability that their child will be a carrier? Will have sickle-cell anemia?
6. One person is **Hb^AHb^A**, the other is **Hb^AHb^S**. What are the chances that their child will be a carrier? Will have sickle-cell anemia?
7. What causes galactosemia? How can the disease be treated?
8. What causes PKU? Can it be treated? Explain.
9. Why does PKU become noticeable only after the baby is born?
10. What causes Tay-Sachs disease? Can it be treated?

Genes and Blood

9–9 Antigens, antibodies, and allergic reactions Human blood is like human fingerprints. No two persons have fingerprints or blood that is exactly alike. The differences in the blood of different persons are the result of different blood proteins that result from different genes. Many of these proteins are antigens and antibodies, which we shall discuss.

Antibodies (an'tē bod ēz) are proteins that are like defensive soldiers in our blood. They attack and destroy foreign substances that enter the bloodstream. Such foreign substances are usually proteins or large polysaccharides, and they are called **antigens** (an'tə jənz). An antigen is defined as a substance, such as a protein or polysaccharide, that stimulates the production of antibodies when it enters the bloodstream. Typical antigens are viruses and bacteria, and the antibodies that attack them protect us from disease.

ANSWERS TO CHECK YOUR FACTS

1. That a person had a normal gene for hemoglobin and a gene for the abnormal hemoglobin of sickle-cell anemia.
2. About 65 percent of the hemoglobin is normal; the rest is abnormal.
3. It causes sickled blood cells, which fragment and jam blood vessels, causing pain and tissue damage.
4. It helps protect against the malarial parasite that destroys red blood cells.
5. $\frac{1}{2}$, $\frac{1}{4}$.
6. $\frac{1}{2}$, 0.
7. The enzyme that breaks down galactose is lacking. The person is given a milk-free diet.
8. The lack of the enzyme that digests phenylalanine. Yes. The person eats a special diet until brain development is complete.
9. Because the mother's liver served to break down phenylalanine prior to birth.
10. The lack of an enzyme that breaks down fatty polysaccharides. No.

MAIN IDEA

Antibodies defend the body against foreign antigens. Antigen-antibody reactions can harm the body in an allergic reaction.

SCIENCE BACKGROUND

Most students have heard of allergic reactions to an antibiotic or to animal bites or bee stings. The first injection of the antigen stimulates the production of antibodies and is called sensitization.

Sometimes antigen-antibody reactions can cause serious problems in humans. These can be demonstrated in laboratory animals. If egg white, which is a protein, is injected into an animal, there is no obvious reaction. But if a similar injection is given again ten days later, the animal will suffer muscle spasms (uncontrollable contractions). Without treatment, the animal may die. The problem was caused by the first injection of egg white, which becomes an antigen as soon as it enters the animal's body. It stimulates the production of antibodies in the blood of the animal. These antibodies are specific for the antigen that caused them to be produced. The next time the egg white enters the blood, the antibodies, like soldiers, are waiting for the attack. Unfortunately they sometimes attack in a violent manner, causing muscle spasms that affect the lungs and heart. Such a reaction is called an **allergic** (ə lēr'jik) **reaction**. If an allergic reaction is severe, it can cause death.

MAIN IDEA

When blood with antigens is mixed with blood that has antibodies for those antigens, an agglutination reaction occurs that can cause death.

SCIENCE BACKGROUND

Karl Landsteiner discovered the ABO factors in 1901 and was awarded the Nobel Prize in 1930.

9-10 The ABO blood antigens It used to be extremely dangerous to give another person's blood to an injured person. Sometimes it saved the person's life, but often it caused a severe type of antigen-antibody reaction. The reaction, called an **agglutination** (ə glü tə nā'shən) **reaction**, caused the red blood cells to clump together, or agglutinate. The person who received the blood could not pump the agglutinated blood through the body and death resulted.

The reason for the agglutination reactions was discovered in the early 1900s. Many people have antigens in their

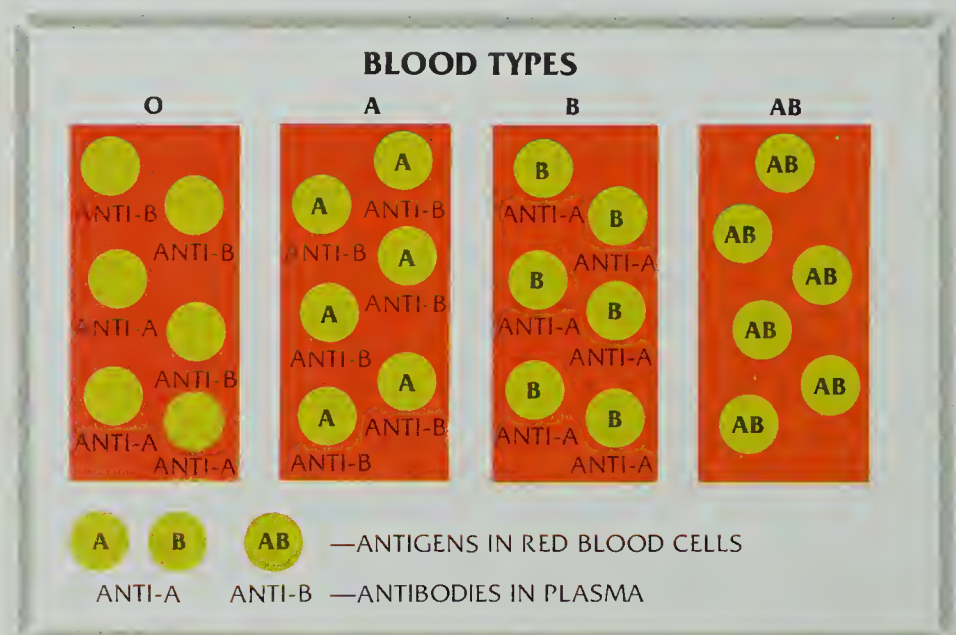


FIGURE 9-1

This figure illustrates the antigen and the antibody composition for the four main human blood groups—A, B, AB, and O.

red blood cells. When these antigens enter another person's blood, they may be attacked immediately by antibodies, which cause the agglutination reaction.

Two different antigens were discovered in the red blood cells. They are called the **A antigen** and the **B antigen**. People are grouped into four blood types according to the antigens they have, or do not have. A person with the A antigen has blood type A. A person with the B antigen has blood type B. A person with both the A and B antigens in the red blood cells has blood type AB. A person with neither A nor B antigens has blood type O.

Another discovery was that people have antibodies in their blood against the antigen or antigens that they do not have in their own red blood cells. A person with type A has an anti-B antibody. If blood from a type B person, which has the B antigen, enters this person's body, the anti-B antibodies will cause an agglutination reaction. Likewise a person with type B blood has anti-A antibodies, and these will agglutinate blood from a type A person. Type O blood has both anti-A and anti-B antibodies. Type AB blood has neither antibody. A laboratory technique called blood typing uses anti-A and anti-B antibodies to determine a person's blood type before blood can be received.

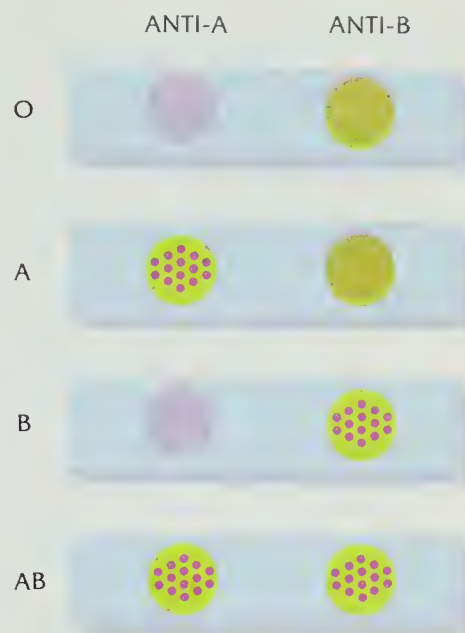


FIGURE 9-2
Antibody A will agglutinate blood of types A and AB. Antibody B will agglutinate blood of types B and AB.

9-11 The inheritance of blood type Human blood type is inherited by a Mendelian pattern and is determined by a two-gene combination of three possible alleles. Allele A produces the A antigen, allele B produces the B antigen, and allele O produces no antigen. A and B genes are codominant, which means that both antigens are produced if a person has those two genes. Also, A and B genes are dominant over the O gene. Thus there are six possible genotypes and four possible blood types (phenotypes).

<i>Genotypes</i>		<i>Phenotypes</i>
AA	—	type A
AO	—	type A
BB	—	type B
BO	—	type B
AB	—	type AB
OO	—	type O

Parents can predict what blood types their children *may* have and what types they will not have. For example, what blood types will result from crossing a type A mother with a type O father? There are two possible genotypes for the mother (AA or AO), but only one for the father (OO).

MAIN IDEA

Three alleles determine the blood antigens. A and B antigens are codominant, while O is recessive. These antigens can be used to predict the blood type of offspring.

SCIENCE BACKGROUND

There are some people who can inherit a gene for developing an A or B antigen but who end up with O blood. This is a rare phenomenon caused by the lack of a gene for making a precursor substance H, which is necessary before the antigen can be produced. Such a person is said to have the *Bombay phenotype*.

SCIENCE TERMS

antibodies
antigens
allergic reaction
agglutination reaction
Rh antigen
rhogam

MAIN IDEA

Exposure of Rh negative persons to Rh antigens causes antibodies to be produced. A second such exposure results in a severe reaction.

MAIN IDEA

The second Rh positive child carried by an Rh negative mother is subject to attack from the mother's antibodies. Rhogam is administered to the mother after the first birth to prevent this problem.

The Rh antigen was originally discovered in rhesus monkeys.



There are two possible results:

	Mother		Father
(1)	AA	x	OO

All children will be **AO** and have type **A** blood.

	Mother		Father
(2)	AO	x	OO

$\frac{1}{2}$ probability children **AO**—type A blood
 $\frac{1}{2}$ probability children **OO**—type O blood

There is zero probability that the children from such a cross will have type B or AB blood.

9–12 Rh antigens In 1940 another important blood antigen was discovered, first in rhesus monkeys, then in humans. It was called the **Rh factor** after the rhesus monkey. Now it is called the **Rh antigen**. About 85 percent of the people of European descent have the Rh antigen and are called **Rh positive**. Those who do not have the antigen in their blood are called **Rh negative**.

Persons who are Rh negative do not normally have anti-Rh antibodies in their blood. Therefore the first transfusion of blood from an Rh positive person is not likely to cause a problem. However, the Rh antigen should stimulate antibody production, and the next time Rh positive blood is received, it could cause a reaction that destroys the foreign blood cells.

9–13 Rh antigen and babies The biggest problem with the Rh antigen is between certain mothers and their developing babies. It all depends upon the genotype of mother, father, and baby.

The Rh positive gene (Rh^+), which produces the Rh antigen, is dominant over the Rh negative gene (Rh^-). A potential problem can result when an Rh positive father (Rh^+Rh^+ or Rh^+Rh^-) produces a child with an Rh negative mother (Rh^-Rh^-). There is either a 50 or 100 percent probability that the child will be Rh positive. That creates a potential problem.

During childbirth there is bleeding when the baby separates from its point of attachment in the mother's body. Usually some of the baby's blood enters the bloodstream of the mother. If the baby is Rh positive, the antigen will stimulate the production of antibodies in the mother's blood. Later, during a second pregnancy, some of those antibodies will cross over into the developing baby's blood. If the second baby also happens to be Rh positive, the antibodies will begin destroying the baby's red blood cells. By the time such a baby is born, it can be suffering from sev-

eral problems. In the past these babies often died unless they received a whole new supply of blood at birth.

Now, with a new treatment, there is little chance that a baby will be born with this type of problem. An Rh negative mother who gives birth to an Rh positive baby is now injected with a substance called **rhogam**. Rhogam contains anti-Rh antibodies. The anti-Rh antibodies react immediately with Rh antigen that might have entered the mother's bloodstream from her baby during birth. Thus there is no chance for her own body to develop anti-Rh antibodies that could get into the bloodstream of her second baby.

CHECK YOUR FACTS

1. What are antibodies? What is their function?
2. What are antigens? Can they be harmful?
3. Why does an allergic reaction occur at the second exposure to an antigen but not at the first exposure?
4. What is an agglutination reaction? Does it occur in every blood transfusion?
5. What are the four blood types? Which type has no antigens?
6. Which blood types have anti-B antibodies? Which type has neither antibody?
7. Explain the order of dominance in the alleles for blood antigens.
8. If the mother is type A and the father is type B, what are the possible blood types for their child?
9. Are the Rh factors common? Explain.
10. When is the Rh factor of concern in bearing children?
11. How does rhogam protect the second Rh positive child of an Rh negative mother?

ANSWERS TO CHECK YOUR FACTS

1. Proteins that attack and destroy foreign antigens in the body. They function to prevent disease.
2. Substances that stimulate the production of antibodies when they enter the bloodstream. Yes, bacteria and viruses can cause disease.
3. Because the first exposure caused the production of antibodies. The second exposure found these antibodies already produced and ready to react.
4. A reaction of antigens to antibodies that causes the red blood cells to clump together. No.
5. A, B, AB, and O. O.
6. A and O. AB.
7. A and B are codominant, and both are dominant over O.
8. Any of the four types is possible if their genotypes are A.
9. Yes, about 85 percent of people of European descent have these antigens.
10. When the mother is Rh negative and the father is Rh positive, particularly when one Rh positive child has already been born.
11. It reacts with the Rh antigens after the first birth before these antigens can stimulate antibody production.

Chromosomes and Heredity

9–14 Sex chromosomes Up to this point in the chapter, we have discussed the effects of individual genes on the heredity of persons. Now we shall discuss how the heredity of a person can be influenced by the effect of whole chromosomes, or parts of chromosomes.

A normal person has 23 pairs of chromosomes, for a total of 46. One pair are the sex chromosomes; the other 22 pairs are autosomes. In the normal female, the pair of sex chromosomes are alike and are called X chromosomes. In the normal male, the pair are unlike. One is an X chromosome like the one found in the female. The second is about

MAIN IDEA

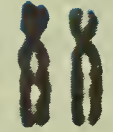
Serious disorders can result from the failure of the sex chromosomes to separate during meiosis.

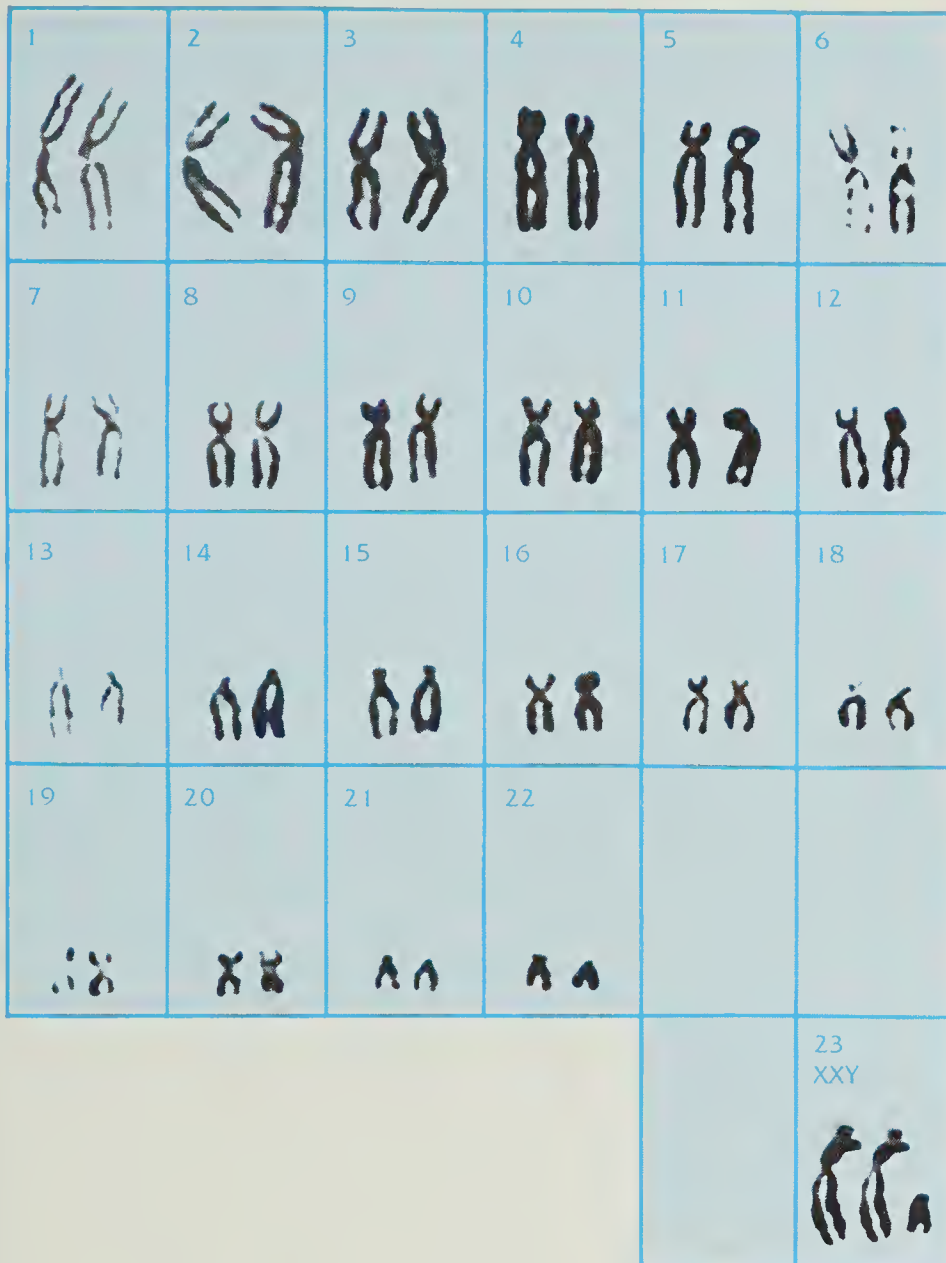
one-fifth the size of the X chromosome and is called a Y chromosome.

During meiosis the X chromosomes sometimes stick together and do not separate during cell division. This can happen during the formation of the female egg cell. It may have either two X chromosomes or no X chromosomes.

The sperm from the father can have either an X or a Y chromosome. If a sperm with an X chromosome combines with an egg that has two X chromosomes, the result will be an individual with three X chromosomes. This condition is called **trisomy** (tri'sō mē) **X**. The trisomy X person is a

The chromosomal makeup of a normal human male is shown below. Note that the twenty-third pair of chromosomes is XY.

1 	2 	3 	4 	5 	6 
7 	8 	9 	10 	11 	12 
13 	14 	15 	16 	17 	18 
19 	20 	21 	22 		23 XY 



The chromosomal makeup of a human male suffering from Klinefelter's syndrome is shown above. This person has three sex chromosomes.

female, and she may be normal. However, many girls born with the trisomy X condition grow up to be sterile, which means that they cannot produce egg cells and therefore cannot reproduce. Also there is at least twice the probability that such a girl will be mentally retarded.

It is possible for an XX egg to combine with a sperm with a Y chromosome. The XXY male is abnormal and suffers from a general condition known as **Klinefelter's** (klīn'fel tərz) **syndrome**. An XXY male is sterile, has some female characteristics, and is likely to be mentally retarded. Klinefelter's syndrome is seen in about 1 in 400 live male births.

SCIENCE BACKGROUND

At this time some cytologists have seen what appears to be a part of the coiled X chromosome of the Barr body that extends outward. This section might contain genes that are being translated. One important question arises as to which X chromosome, and consequently which genes, will be expressed in the female. The Mary Lyon hypothesis suggests that the Barr bodies form sometime after conception and that the female is a mosaic, with the descendants of some cells expressing genes from one X chromosome and the descendants from other cells expressing genes from the other X chromosome.

SCIENCE BACKGROUND

Acridine dyes are used to stain cells for the detection of the Y chromosome. It is becoming more and more routine to check the cells of the newborn for Barr bodies. Certain cells from the cord, called Wharton jelly cells, are used for Y chromosome study.

Another possibility is that the egg with no X chromosome will combine with a sperm with an X chromosome. The resulting female, called an XO female, suffers from a condition called **Turner's syndrome**. The female will be sterile, but with hormone treatment she can develop into a well-adjusted person. Many developing babies are shed from the mother's body after only a few weeks or months of development. This is called a miscarriage, or, more properly, **spontaneous** (spon tā'nē əs) **abortion**. Many spontaneous abortions are XO girls. Only about 5 percent of the XO's survive to be born alive.

A human female suffering from Turner's syndrome has only 45 chromosomes per cell. She has a single sex chromosome.



Sometimes the Y chromosome may not separate during the formation of sperm cells. This can result in the uniting of a YY sperm and an egg with one X chromosome, uniting with a single-X egg which produces an XYY male. This is fairly common, with an estimated 1 in 400 live male births being XYY males. The XYY adult is generally taller and may be mentally retarded to some degree. Researchers are trying to determine other ways that the XYY chromosomes might affect such males.

9-15 Barr bodies and sex determination In 1949 Murray Barr of the University of Western Ontario, Canada, made an important discovery. He was studying cells from female cats and saw a dark body lying against the nuclear membrane. After considerable research he found that cells from females, including humans, have the dark bodies, while male cells do not. The dark bodies are called **Barr bodies**.

Now we know that the Barr body is one of the X chromosomes that is tightly coiled. Probably the genes from all or part of this coiled chromosome are not being translated. Hence, in a female only the genes from one of the X chromosomes is supplying information to the cells.

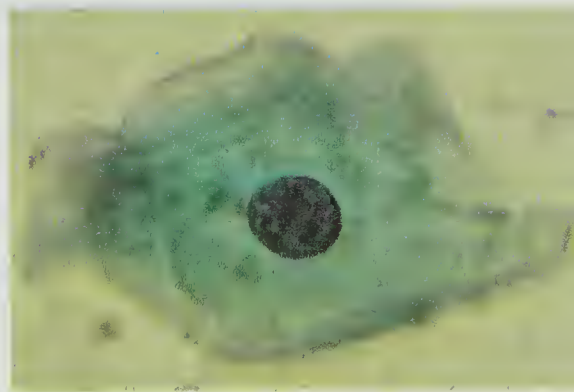
9-16 Detecting Y chromosomes The Y chromosome is mostly made up of a special kind of protein and contains only a small amount of DNA. A simple test, using a stain that is selective for the special protein in chromosomes, causes the Y chromosome to show up as a bright spot. (They must be viewed with a special ultraviolet light microscope.) This test has many uses, but one sometimes makes the sports news headlines. Occasionally a male will try to compete with females in an athletic event. Now, using this test on the cells at the base of a hair, the presence of a Y chromosome can be detected. Most athletes competing in the women's events in the Olympics will probably always have to take such a test.

9-17 Sex-linked traits Some human characteristics are sex-linked traits that are determined by genes on the X chromosome. An example is **red-green color blindness**, of which there are two types. With one type, a person has difficulty detecting the color green and confuses it with red. However, in bright light and with bright colors the person can often see the green color. About 75 percent of red-green color blindness is of this type.

The second type of red-green color blindness is more severe, with red and green confused under all conditions.

MAIN IDEA

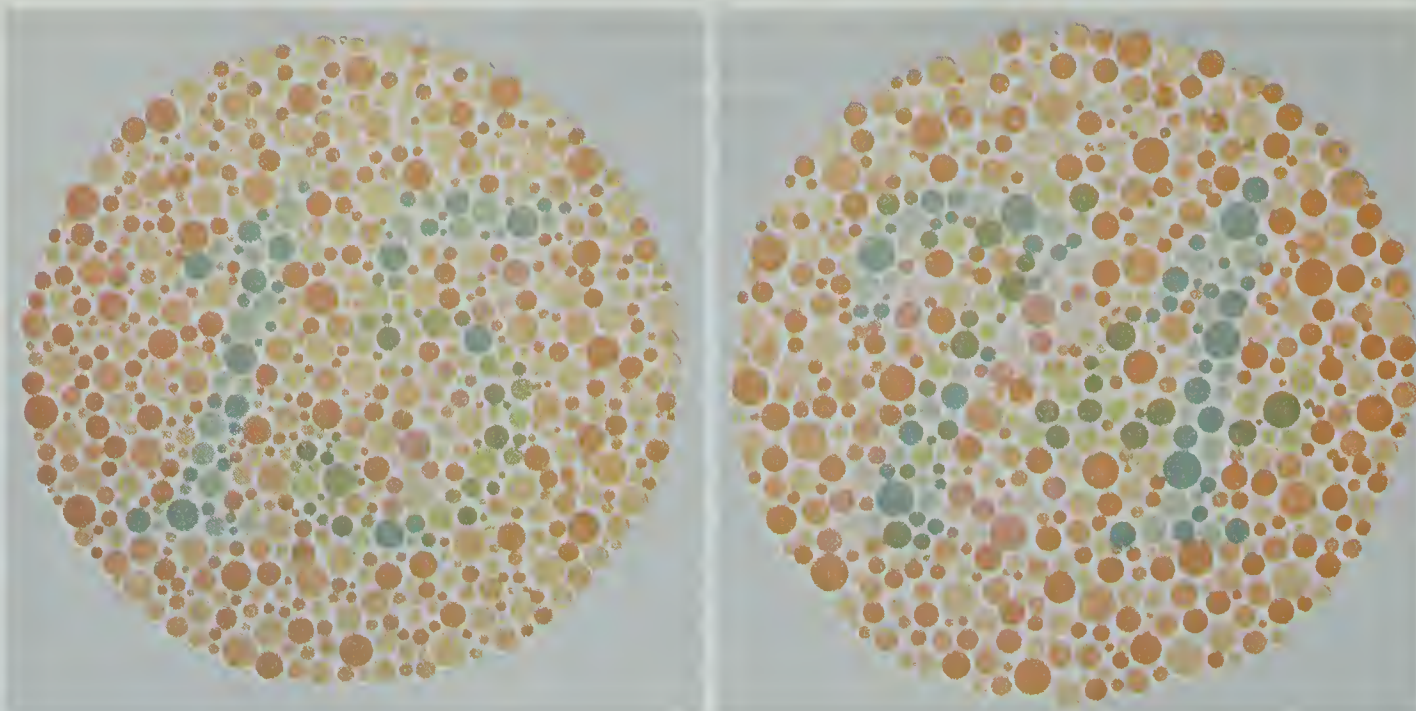
When more than one X chromosome is present in the cell, all but one coil up to form Barr bodies.



The Barr body, seen only in female cells, is one of the X chromosomes that is tightly coiled and lying against the nuclear membrane.

MAIN IDEA

Red-green color blindness and hemophilia are sex-linked traits. Both appear mostly in males.



Images such as these are used to detect various forms of color blindness. Can you see the numbers?

SCIENCE BACKGROUND

Red-green color blindness is caused by defective function of the green-sensitive cones in the retina. The common type is called deuteranomaly; the less common type is deuteranopia. Hemophilia is caused by the lack of a plasma protein called antihemophilic globulin (AHG), or Substance III. It is a precursor substance needed to initiate the complex clotting mechanism. Patients are now given injections of the missing factor, which have been taken from the plasma of donors.

The first type of color blindness occurs in about 8 percent of all boys, which is a ratio of about 1 in 12. In contrast, the problem exists in only 0.4 percent of girls, which is a ratio of 1 in 150.

Now we know that the gene for red-green color blindness is a recessive gene on the X chromosome. Rarely do girls get two X chromosomes, both with recessive genes. But in a male, with only one X chromosome, the recessive gene is expressed as though it were a dominant gene.

The inheritance of sex-linked traits normally follows an alternate generation pattern. For example, a man with red-green color blindness will pass the gene on to all his daughters. (He cannot pass it to a son because he gives a son a Y chromosome.) The daughter usually will not have the problem, but there is a 50-50 chance that her sons will get the X chromosome with the “bad” gene.

Hemophilia, or bleeder’s disease, is also sex-linked. Persons with this disease are mostly male, and the inheritance pattern is similar to that of the red-green color blindness gene. Luckily hemophilia is quite rare, and modern treatments can usually prevent the victim from bleeding to death. That used to be the fate of many persons with the disease. Hemophilia is interesting from a historical standpoint because Queen Victoria of Great Britain passed the gene on to many royal offspring.



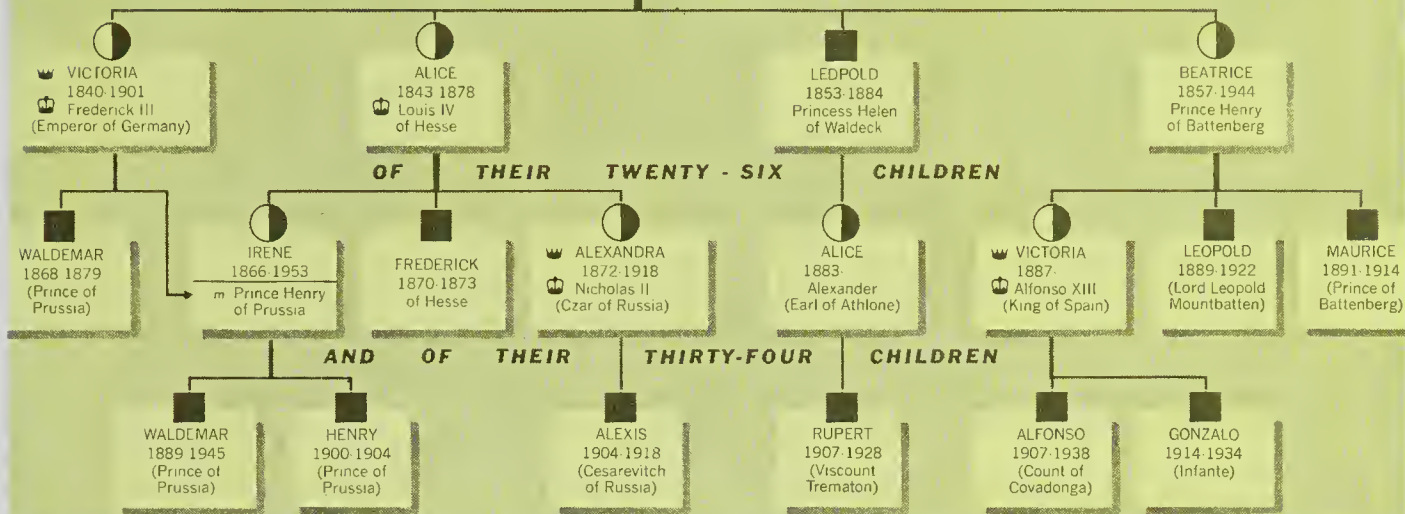
QUEEN VICTORIA
1819-1901
m Prince Albert

☞ CROWNED
HEADS

◐ FEMALE
CARRIER

■ MALE
HEMOPHILIAC

OF HER NINE CHILDREN



- | | | |
|---------------------------------|--|---|
| 1 Prince Louis of Battenberg | 11 Princess Philip of Saxe Coburg | 21 Princess Alexandra of Hesse |
| 2 Grand Duke Paul of Russia | 12 Grand Duke Vladimir of Russia | 22 Princess Louis of Battenberg |
| 3 Prince Ferdinand of Romania | 13 Duke of Connaught | 23 Princess Henry of Prussia |
| 4 Count Mensdorff | 14 Prince of Wales | 24 Grand Duchess Vladimir of Russia |
| 5 Grand Duke Serge of Russia | 15 Princess Henry of Battenberg | 25 Duchess of Saxe Coburg-Gotha |
| 6 Princess Ferdinand of Romania | 16 Princess Alexandra of Saxe-Coburg-Gotha | 26 Kaiser Wilhelm II |
| 7 Prince Henry of Prussia | 17 Hereditary Princess of Saxe-Meiningen | 27 Queen Victoria |
| 8 Grand Duchess Serge of Russia | 18 Duchess of Connaught | 28 Empress Frederick of Germany |
| 9 Duke of Saxe-Coburg-Gotha | 19 Prince Alfred of Saxe-Coburg-Gotha | 29 Princess Beatrice of Saxe-Coburg-Gotha |
| 10 Prince Henry of Battenberg | 20 Cesarevitch | 30 Princess Feodore of Saxe-Meiningen |

MAIN IDEA

Down's syndrome, Edward's syndrome, and Patau's syndrome are rare trisomys that do not immediately cause death. All cause retardation and early death.

SCIENCE BACKGROUND

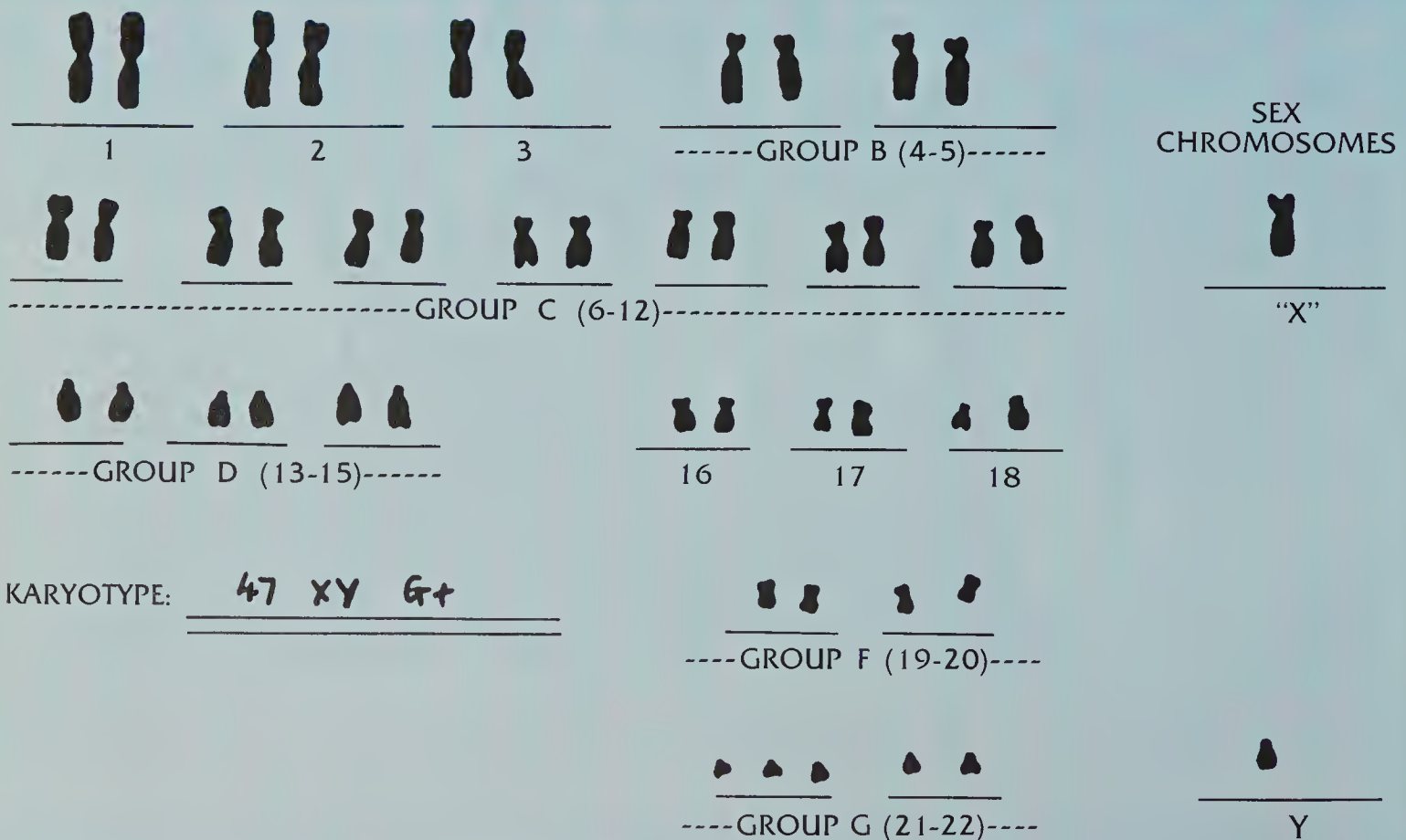
One type of Down's syndrome can be inherited. This occurs in about 3.5 percent of cases where a victim has the normal 46 chromosomes, but one chromosome is longer because a chromosome-21 or part of a chromosome-21 has become attached. The effect is trisomic, and the aberration can be passed on.

9-18 Chromosome aberrations A **chromosome aberration** (ab ə rā'shən) is any kind of chromosome abnormality. This includes multiple chromosomes, broken chromosomes, and chromosomes with extra chromatin attached to them. We have already mentioned such chromosome aberrations as XXX, XXY, XO, and XYY, which are aberrations of the sex chromosomes.

It is estimated that about 40 percent of human spontaneous abortions are the result of chromosome aberrations. Usually the aberration is more than the normal number of chromosomes. However, in three types of aberrations there is some hope for survival. These are three different trisomys (three instead of two chromosomes).

Each of the 22 pairs of autosomes has been numbered and classified according to its individual structure. Thus one trisomy is recognized as trisomy-21, a condition where there are three number-21 chromosomes. The individual

Individuals suffering from Down's syndrome have 47 chromosomes per cell. There are three number-21 chromosomes present.



that results is abnormal and is said to have **Down's syndrome**. Such an individual is shorter than normal and has a rounded face and a folded upper eyelid. The person also has a large tongue, which makes speaking difficult, and suffers from mental retardation. The incidence of Down's syndrome increases with maternal age. This is discussed in the next section. In past years about half the children born with this syndrome died from respiratory disease or heart problems in the first year. Now, surgery and antibiotics enable many to live much longer.

A second autosome trisomy is trisomy-18, which is described as **Edward's syndrome**. A child born with three number-18 chromosomes has many problems including severe mental retardation. The average survival time for such a child is 10 weeks. A third trisomy, trisomy-13 or **Patau's syndrome**, is even worse, with survival time of only a few weeks.

9-19 Trisomy and maternal age Trisomy-21, or Down's syndrome, is the most common chromosomal aberration. Today we have statistics that show when the condition is most likely to occur in children. The occurrence is only 1 in 1 500 when the mothers are in their twenties. But this ratio increases greatly when forty-year-old women have children, jumping to 1 in 80. The probability of occurrence increases almost 100 percent when a mother is just five years older. Women of forty-five have the risk that 1 in 44 births will produce a child with trisomy-21. Altogether about 40 percent of all babies born with trisomy-21 are born to mothers who are over forty. Maternal age (the age of the mother) is also related to the other two trisomys, which are much rarer.

Researchers are not sure why older women should have a higher risk of children with a trisomy aberration. Some speculate that the extra chromosome results because there are many years between meiosis I and meiosis II in the formation of the egg. The age of the father seems to have no effect, and this may be because meiosis I and meiosis II occur immediately during sperm development.

9-20 Heredity or environment? For many years, people have debated the importance of heredity and environment on the development of a person. There is no clear-cut answer to either side of the debate, but it is important to understand the role of each. This role can be summarized in one sentence: The genes that a person inherits determine what that person *may* become; the environment determines what that person *will* become.

SCIENCE TERMS

trisomy-X
Klinefelter's syndrome
Turner's syndrome
spontaneous abortion
Barr bodies
red-green color blindness
chromosome aberration
Down's syndrome
Edward's syndrome
Patau's syndrome
teratogens

MAIN IDEA

Down's syndrome increases enormously among births to women over forty, possibly because of the long interval between meiosis I and meiosis II

MAIN IDEA

The potential of a person is largely determined by genes. Environmental factors can limit this potential. Teratogens can damage genes during pregnancy

ANSWERS TO CHECK YOUR FACTS

1. 22.
2. A condition in which the cells contain three X chromosomes. The person is female, is often sterile, and is likely to be mentally retarded.
3. Klinefelter's syndrome.
4. It is seen in an XO female. The person is completely sterile

5. They are usually taller and may be mentally retarded.
6. Coiled X chromosomes. In XXX females.
7. Chromosome stains cause the Y chromosome to appear as a bright spot under an ultraviolet light microscope.
8. On the X chromosome.
9. Because a female will carry the gene that is expressed in her father and then later in her sons without expressing the recessive gene herself. Boys do not get an X chromosome from their father.
10. Any chromosome abnormality.
11. XO is Turner's syndrome; it produces females. XXY is Klinefelter's syndrome; it produces males.
12. The person suffers from mental retardation; has a rounded face, large tongue, and a folded upper eyelid; and is shorter than normal. Down's syndrome and Mongolism.
13. Trisomy-18, or Edward's syndrome, and trisomy-13, or Patau's syndrome.
14. When the mother is forty or over. Perhaps because of the long period between meiosis I and meiosis II.
15. Because it can cause serious birth defects.

ANSWERS TO REVIEW QUESTIONS

1. Because they are polygenic and have a continuous range of expression.
2. Usually the dominant gene produces a normal polypeptide and the recessive gene produces a polypeptide that does not function or that functions poorly.
3. $\frac{1}{50}$. $\frac{1}{50} \times \frac{1}{50}$, or $\frac{1}{2500}$.
4. No. This is an example of codominance, where the heterozygote produces some

As an example, a person may inherit genes that could make him or her grow very tall. But if the child goes without proper food during pregnancy and its early years, it might grow only to an average height. Likewise, a child could be born with the genes to become a brilliant artist or musician. But the environment could deprive the child of any opportunity to develop those abilities. The same can be said for levels of general intelligence. To some unknown degree, intelligence is inherited. But intelligence is also strongly influenced by the environment of a child. Without proper opportunities, a child may never develop the intelligence that its genes gave it the potential to have.

Environment can also be involved in changing the heredity of an individual. For example, various substances called **teratogens** (ter'ə tə jənz) can cause gene and chromosome damage in a developing baby during pregnancy. One very strong teratogen is radiation from X rays. Another teratogen is alcohol which, if drunk in heavy amounts, can cause serious birth defects. Other suspected teratogens are LSD and marijuana. Generally, pregnant women are advised to avoid all drugs that are not specifically prescribed by their physicians.

CHECK YOUR FACTS

1. How many pairs of autosomes are in human cells?
2. What is trisomy X? What are the results?
3. What results when an XX egg unites with a Y sperm?
4. Describe Turner's syndrome.
5. What is the effect of an extra Y chromosome in males?
6. What are Barr bodies? What cells have two Barr bodies?
7. How is the presence of a Y chromosome detected?
8. Where are the alleles for hemophilia and red-green color blindness carried?
9. Why do sex-linked traits follow an alternate generation pattern? Why don't boys inherit sex-linked traits from their father?
10. What is a chromosome aberration?
11. What are the names for these chromosome aberrations: XO, XXY? Do they produce males or females?
12. Describe trisomy-21. What are other names for this problem?
13. Name two other trisomys.
14. When is trisomy-21 most likely to occur? What might be the reason for this?
15. Why should pregnant females avoid drinking large amounts of alcohol?

SUMMARY

While discontinuous traits are easily analyzed, polygenic continuous traits are very difficult to understand and define. Dominant, or “good,” genes usually code for normal polypeptides. Recessive, or “bad,” genes generally produce faulty polypeptides. Genetic diseases usually result when the body must rely on these faulty polypeptides and the enzymes they make up. Albinism results from two recessive genes. Sickle-cell anemia results when both chromosomes have a recessive gene that cannot code for normal hemoglobin.

REVIEW QUESTIONS

1. Why are continuous traits more difficult to predict and analyze than discontinuous traits?
2. What is the functional difference between a dominant gene and a recessive gene?
3. What is the chance that two normally pigmented parents will be heterozygous for albinism? Both parents?
4. Is Hb^s a recessive allele? Explain.
5. What is the probable reason why the sickle-cell gene has not become as rare as most other harmful genes?
6. What risks are involved when parents who are both carriers choose to have children?
7. Describe the cause and symptoms of phenylketonuria. When is special treatment needed?
8. List the antigens and antibodies found in each of the four blood types: A, B, AB, and O.
9. Martha has type A blood. Her baby has type O blood. Jim has type A blood, but both of his parents had type AB blood. Can Jim be the father of Martha's child?
10. The father is Rh positive and the mother is Rh negative. If they wish to have several children, what risks should they consider?

ANALYSIS AND APPLICATION

1. Can you explain why we do not find such chromosome aberrations as trisomy-5, trisomy-2, or trisomy-20?
2. Under what circumstances could a female inherit hemophilia?
3. Suppose a teratogen, such as alcohol, caused the change of only one nucleotide pair in a developing child's DNA. Since there are millions of nucleotide pairs, could the damage to just one pair possibly be important? Explain.
4. Why are traits such as eye color, skin color, hair color, tallness, and intelligence not as predictable as blood type?

quantities of abnormal hemoglobin.

5. Because the gene is also a beneficial gene to those populations that are exposed to malarial parasites.

6. There is a $\frac{1}{4}$ chance of a child being homozygous with genotype $Hb^s Hb^s$.

7. It is caused by the lack of an enzyme that breaks down phenylalanine. Improper brain development results. A special diet is used until the brain is developed—around the age of nine. This diet is resumed when affected females become pregnant.

8. Type A: A antigens and anti-B antibodies. Type B: B antigens and anti-A antibodies. Type AB: A and B antigens and no antibodies. Type O: no antigens and anti-A and anti-B antibodies.

9. No. Jim's genotype is AA. Since the genotype of the child is OO, Jim could not be its father.

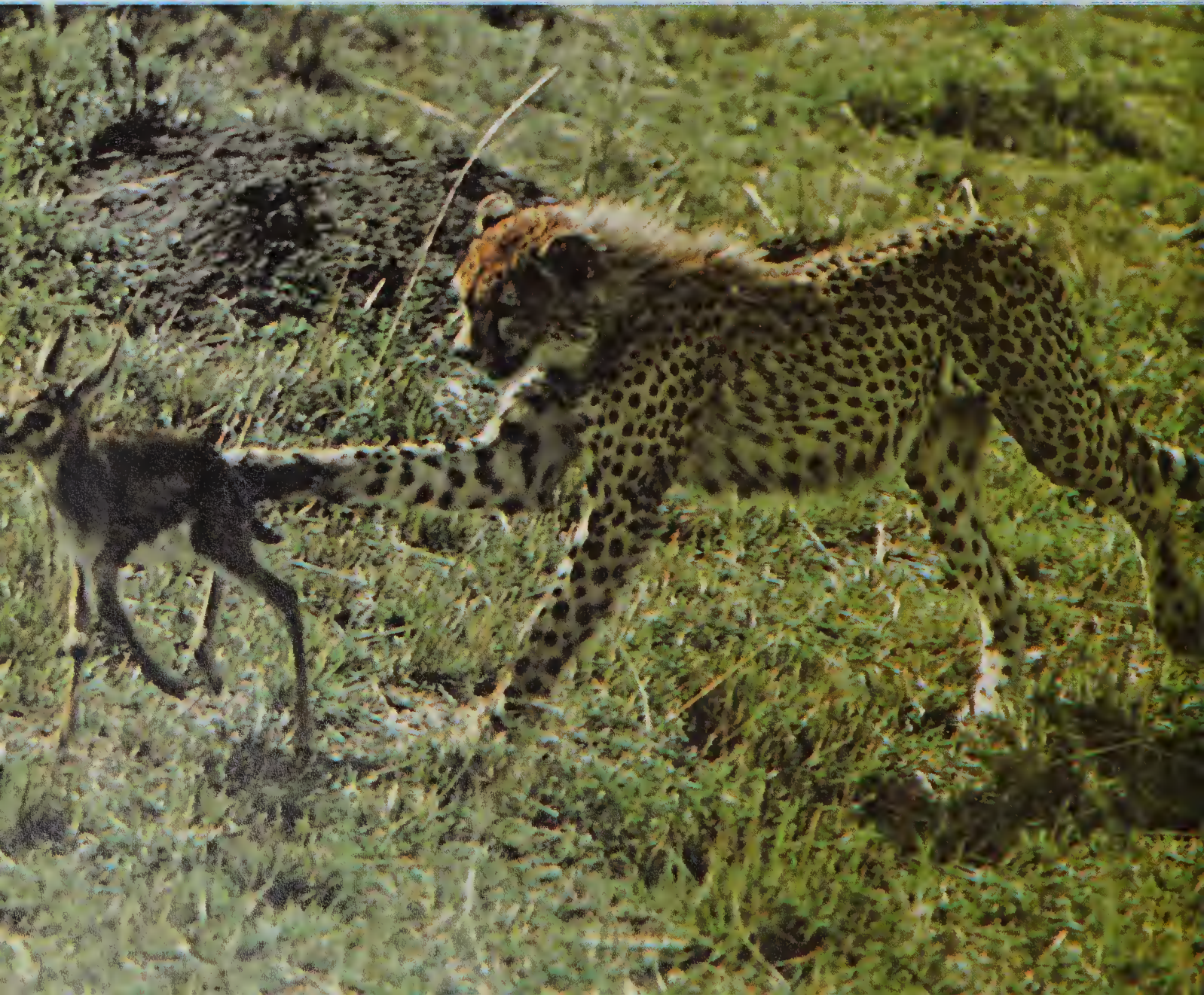
10. The first Rh positive child and all Rh negative children are usually not endangered by the Rh factors.

ANSWERS TO ANALYSIS AND APPLICATION

1. Because they probably cause spontaneous abortion.
2. If a female heterozygote, or carrier, is the mother and the father is hemophilic, there is a $\frac{1}{2}$ probability that the daughter will have hemophilia.
3. Absolutely. One nucleotide pair is one third of a codon for some amino acid. Just one amino acid improperly placed in a polypeptide could cause a major problem.
4. Because all these traits are continuous traits and are polygenic, they are not inherited by Mendelian patterns.

Investigation 23 from *Laboratory Investigations in Biology* can be done with this chapter.

10 *Natural*



OBJECTIVES

- To appreciate the role of natural selection in producing adaptation in organisms
- To understand that adaptations have been created by the process of artificial selection
- To describe the two-step nature of the process of natural selection
- To know two examples of how natural selection has created adaptations in natural populations
- To explain the difference between the process of evolution and the theory of evolution

Selection

Natural Selection

10-1 An important concept The idea, or concept, of **natural selection** is one of the most important concepts of biology. It is important because it explains how populations of organisms develop adaptations. For example, many disease-causing bacteria were killed by small doses of penicillin when this drug was introduced in the mid-1940s. But these bacteria slowly developed an adaptation. This adaptation was a resistance to penicillin. As each year passed, larger and larger doses of penicillin were needed to kill the bacteria. Now, after only a few decades, many of those bacteria are almost resistant to penicillin. Like all adaptations, this one gives the bacteria a better chance of surviving in their environment. The method by which they developed this adaptation will be explained.

10-2 Artificial selection The first step in understanding natural selection is to see how people have purposely created adaptations in populations. An example is shown in the way in which animal breeders developed the egg-laying adaptation of the White Leghorn chicken. In 1933 the average yearly egg production of a White Leghorn hen was 125.6 eggs. At that time breeders began to make use of a fact that is true of all populations: *All individuals in a population are unique and unlike any others in the population.* Because of this fact there was a difference, or variation, in egg production among different White Leghorn hens. The average was 125.6 eggs per year. But some produced more and others produced less.

MAIN IDEA

The concept of natural selection is important because it explains how populations of organisms develop adaptations.

SCIENCE BACKGROUND

Staphylococcus and other coliform bacteria developed a resistance to penicillin. These bacteria produce an extracellular enzyme, *penicillinase*, which breaks down this protein, and conceivably was useful as a protective enzyme against other foreign proteins.

MAIN IDEA

Artificial selection involves the breeding of those individuals in a population that have a desired trait to produce more offspring with that trait. This procedure can eventually produce an entire population with the trait.



The average yearly egg production of White Leghorn hens nearly doubled over a period of 30 years as a result of selective breeding.

SCIENCE BACKGROUND

There are numerous examples of artificial selection that would be meaningful to students, such as the varieties of dogs, horses, and cows.

The breeders selected offspring from hens that had the highest egg production. They bred them, and with each generation they selected the best egg producers and bred their offspring. Thirty-two years later, in 1965, they had increased the average yearly egg production of White Leghorn hens to 249.6. This was an average increase of 124 eggs per year.

The technique used by the animal breeders is called **artificial selection**. The term *artificial* refers to the fact that breeders purposely select the pairs to be bred rather than let the breeding occur naturally. The basic technique involves two steps. The first step is to select from within a population the adaptation that we wish to develop. For example, if we want to develop a population of fast horses, we must first select the fastest horses from the population. The second step is to preserve and breed the best offspring from those that were selected, and to continue the process. Of course, that is exactly what racehorse breeders do.

10–3 Natural selection Natural selection also is a two-step process. But it occurs in natural populations, or populations where the breeding is not controlled by people.

The first step in natural selection is the production of variation. There are two ways this occurs in natural populations. One way is by mutation, which is a change in one or more genes of an organism. Mutation is the ultimate source of all variation in populations. The second way variation is produced is by recombination, which occurs during sexual reproduction. Recombination is the exchange of genes that occurs between chromatids during the process of meiosis.

The second step in natural selection is the testing of this variation in the environment. The testing causes some offspring to survive and reproduce and causes others to die. The testing process sometimes seems cruel, but it has to occur. This is because the parents in most natural populations produce far more offspring than can survive or than the world can tolerate. A single pair of frogs will produce thousands of eggs, but only a tiny fraction survive to become adult frogs. An orchid plant produces thousands of seeds, but few will survive to reproduce more orchids. If all the offspring lived and continued to reproduce, the world would soon be buried by frogs and orchids.

Which offspring of the many produced are most likely to survive? The answer to that question determines the type of adaptation that will be developed. Frog tadpoles with a body color that would hide them from predators could be the most likely survivors. Orchid seeds that can survive several months of dry weather might also be the likely survivors. *It is the adaptation that has survival value that is likely to be preserved in any offspring.* In turn, the survivors will pass along the genes for this adaptation to some of their offspring. Then the adaptation is tested again. Those with the best adaptations survive to reproduce and continue the process. You can now understand that over a period of years nature selects and develops adaptations just as a plant or animal breeder does.

10–4 The example of the peppered moth The development of an adaptation by natural selection usually takes longer to occur than by artificial selection. However, the development of some adaptations by natural selection has occurred rapidly enough to have been observed and studied.

An example is an adaptation of the peppered moth of England. The members of the original population were

MAIN IDEA

Those adaptations that help certain offspring to survive until adulthood will tend to appear more frequently in future populations.

SCIENCE BACKGROUND

On the matter of parents producing more offspring than can survive or than the world can tolerate, consider the example of elephants that Darwin used in *The Origin of Species*. He said: “The elephant is reckoned the slowest breeder of all known animals, and I have taken some pains to estimate its probable minimum rate of natural increase; it will be safest to assume that it begins breeding when thirty years old, and goes on breeding till ninety years old, brings forth six young in the interval, and survives till one hundred years old; if this be so, after a period of from 740 to 750 years there would be nearly nineteen million elephants alive, descended from the first pair.” The world would indeed have a difficult time tolerating 19 million elephants.

MAIN IDEA

As trees darkened, the darker peppered moths had a selective advantage, and more of them and their dark offspring were able to survive than were the lighter moths. A population of dark moths has resulted.

The light-colored moth stands out more clearly against the soot-covered bark. Its chances of being spotted by a predator are increased.



SCIENCE BACKGROUND

The general adaptation of the peppered moths is called *industrial melanism*. This adaptation has been developed by 70 other British species and more than 40 species near the manufacturing cities along the St. Lawrence River in Canada.

mostly colored a light gray, speckled with black. The normal resting place of the moths during the day is on trees covered with a gray lichen, a plantlike growth. On such trees the moths are almost impossible to see. This color adaptation helps them survive bird predators.

In 1848, near the industrial city of Manchester, a black peppered moth was found. In less than 50 years, 98 percent of the peppered moths near Birmingham were black. The logical question that follows is, Why should the peppered moths near Birmingham possess the dark-colored adaptation?

Biologists always answer any question concerning the “why” of adaptations with another question. The biologist must ask, What selective advantage did the black color provide for the peppered moths near Birmingham?

The answer to this question was easy to discover and prove. All the industries in the Birmingham area burned coal. Over a period of years, coal dust, or soot, had settled on the trees, killing the lichens and turning the trunks and branches black. Later experiments proved that black moths on the black trees survived bird predators better than light-colored moths on the black trees.

How did natural selection cause the development of the black moths? It did so by the two steps described earlier. First, variation was produced within the original peppered-moth population. Each moth had its own unique color, some lighter and some darker than others. By the second step, the variation in colors was tested in the environment. Nature selected those that had an advantage as



On lichen-covered bark, the dark-colored moth stands out more clearly. The light-colored moth has a better chance of surviving.

the trees turned darker. The moths that were the darkest color had the best chance to survive and pass that trait on to their offspring. As the trees turned darker the testing and selection continued, with the darkest individuals always surviving. The result, after many generations, was a new adaptation in the population—the black moth.

10–5 DDT and flies Another example of natural selection has been observed in the common housefly population. During World War II the chemical called DDT was developed and used to kill mosquitoes and other insect pests. After the war it became widely used to kill many household pests, including the common housefly. In a few years insect populations all over the world developed an adaptation that protected them from the chemical.

The development of the DDT-resistant adaptation can be explained by the two-step process. First, variation was produced in the population. For example, there was variation in the body chemistry of the different flies. A few had a type of body chemistry that protected them from the poisonous effects of DDT. Most of the others had no such natural protection. Second, those with the protective body chemistry survived the test of the environment—the spraying with DDT. The others did not. The survivors, all with natural protection, reproduced among themselves. In the process they passed along their protective genes to most of their offspring. Then, after a few years, most of the flies in the population were of one kind. This was a fly with an adaptation for surviving DDT.

MAIN IDEA

DDT killed flies that were not resistant to the chemical. This left flies that were resistant, and their descendants have formed new populations that are mostly resistant to DDT.

MAIN IDEA

Although both Darwin and Wallace published their ideas on natural selection at about the same time, Darwin is credited with having been the first to develop the concept.

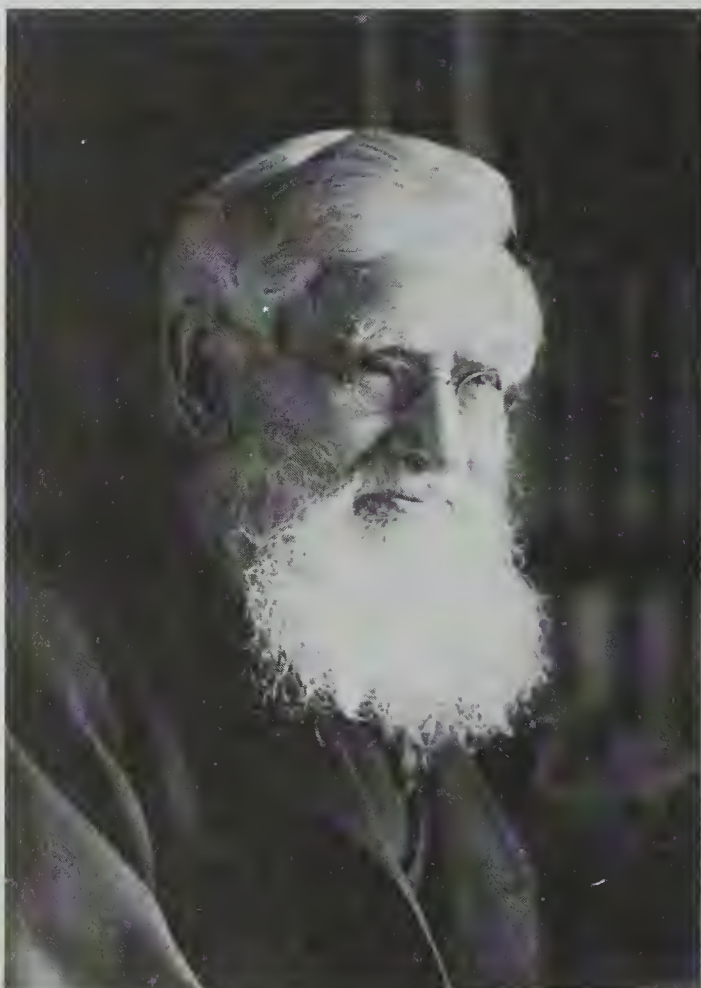
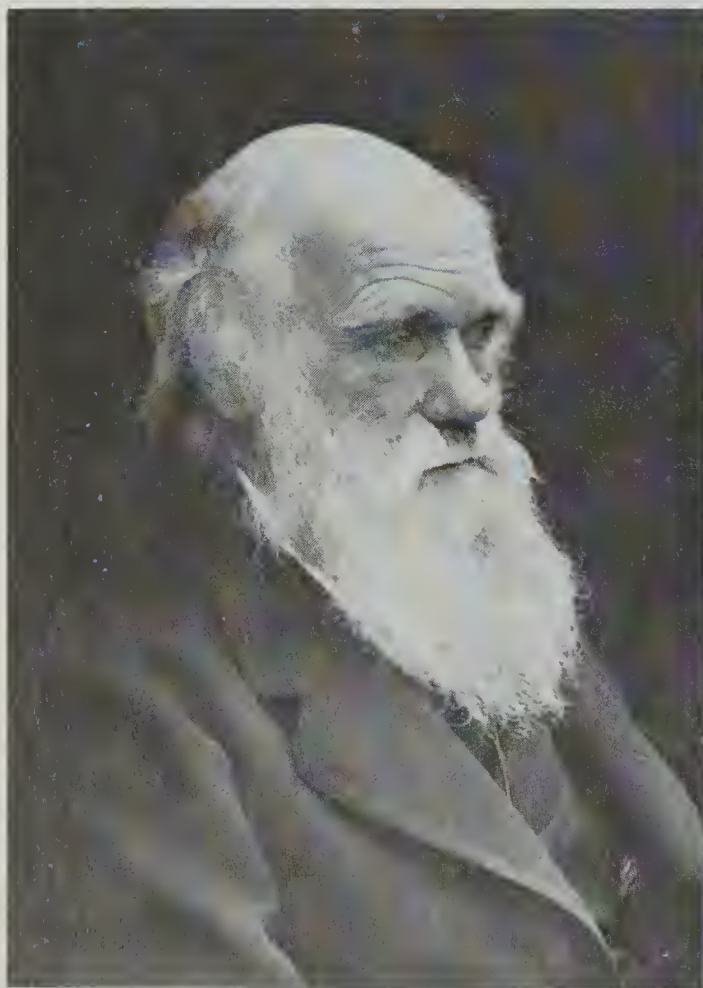
SCIENCE BACKGROUND

Besides *The Origin of Species*, which is fascinating reading, an excellent book for background reading is *Charles Darwin* by Gavin De Beer, in British Men of Science Series (1964; reprint ed., Westport, Conn.: Greenwood Press, Inc., 1976). This describes Darwin's life and the coincidence of Wallace's codiscovery of natural selection.

10-6 Darwin Versus Wallace In 1831 Charles Darwin sailed from his native England on a round-the-world exploration. Darwin was hired as the ship's naturalist. His job was to collect and identify as many plants and animals as possible. But the voyage also stimulated his thinking about adaptations and the different forms of life that he observed. After the voyage Darwin spent most of his life developing and explaining the concept of natural selection.

Darwin's first book on natural selection, *On the Origin of Species*, was published in 1859. This was one year after Alfred Russel Wallace had given Darwin a paper that also explained natural selection. However, Darwin had actually developed the concept of natural selection many years before Wallace had. Given evidence of this fact, other scientists of the time said that Darwin should receive most of the credit. That is certainly how the majority of biologists feel today.

Both Charles Darwin (left) and Alfred Wallace (right) developed the concept of natural selection independently.





Darwin's ideas on natural selection arose partially from studies of variation in beaks of 13 species of finches from the Galápagos Islands.

10-7 Darwin, evolution, and natural selection Today Darwin is often thought of as the father of evolution, or the father of the theory of evolution. Neither would be a correct title for him. To explain, we must define **evolution** (ev ə lū'shən) and understand what Darwin's concept of natural selection has to do with it.

First, evolution can be defined in two ways. By one definition, evolution is the process by which populations change and develop adaptations. By this definition, evolution is a fact, for we have observed population changes and the development of adaptations. We have seen populations of cattle, roses, and White Leghorn hens develop adaptations by artificial selection. We have seen populations of peppered moths, bacteria, and houseflies develop adaptations by natural selection.

The second definition of evolution more correctly refers to the **theory of evolution**. The theory of evolution states that all organisms today have evolved from related organisms that lived in the past. Further, the theory holds that all organisms have evolved from life that formed under natural conditions on the primitive earth.

Charles Darwin was not the father of the theory of evolution. Many scientists before Darwin contributed a great amount of evidence to support the theory. But unfortunately we do not have a time machine that will allow us to see exactly what has happened in the past. Therefore the theory of evolution is strictly a theory and will always remain so.

MAIN IDEA

Darwin contributed to, but did not originate the theory of evolution. This theory states that all life forms evolved from previous forms and that the first life forms originated under natural conditions on the primitive earth. Natural selection has many applications in many areas.

SCIENCE BACKGROUND

It is important to stress the difference between evolution as the process that creates adaptations, and the *theory of evolution* as an explanation for the origin and evolution of life forms. Also it is important to stress the fact that natural selection has an importance to biology that goes far beyond its role in explaining how organisms could have evolved through time.

SCIENCE TERMS

natural selection
artificial selection
evolution
theory of evolution



The concept of natural selection is important in many areas of biological research, such as the effects of antibiotics on bacterial populations.

ANSWERS TO CHECK YOUR FACTS

1. Because it explains how populations develop adaptations.
2. That breeding pairs are selected instead of letting the organisms pair naturally.
3. By gene mutations and by recombination of genes during meiosis. Variety is necessary so that natural selection will have different adaptations to select for survival.

ANSWERS TO REVIEW QUESTIONS

1. Because overpopulation would result if they all survived.
2. Because the trait hid them from predators and had thus

However, it is true that Darwin did contribute evidence to support the theory of evolution. And natural selection does give the paleontologist a way of explaining how life could have evolved in the past. But it would be wrong to relate Darwin's work only to the theory of evolution. Natural selection is extremely useful to a wide variety of biologists and others who deal with life. Ecologists use natural selection to predict how spraying to kill forest pests could create more serious pests. Researchers rely on natural selection to explain the evolution of bacteria and viruses. Farmers have to think about natural selection when they fight boll weevils that destroy their cotton. Plant breeders consider natural selection when developing disease-resistant strains of wheat to feed a hungry world. To summarize, natural selection would still be one of the most important concepts in biology even if we had never heard of the theory of evolution.

CHECK YOUR FACTS

1. Why is natural selection such an important concept in biology?
2. What is meant by artificial selection?
3. How is variation produced in a population? Why is variation necessary for natural selection?

SUMMARY

The concept of natural selection is one of the most important concepts in biology. It explains how populations develop adaptations. Mutations and recombination of genes produce variety within a population. Traits that enable certain offspring to survive and reproduce will be preserved in the population, while individuals without these traits will disappear from the population. Artificially selected hens and naturally selected black moths are examples of how an entire population can acquire a certain adaptation. Natural selection enables populations of bacteria and pest insects to resist our attempts to control them. Darwin and Wallace both developed the concept of natural selection. However, Darwin is given credit for developing it first. Darwin contributed to the theory of evolution, but he did not originate the theory. The theory states that all life is evolved from related forms that lived in the past.

REVIEW QUESTIONS

1. Why is it necessary for many offspring to die in most populations?
2. How can natural selection explain the original gray color of the peppered moths? What happened to the gray moths as the trees turned darker?
3. Why didn't DDT kill all the flies in the population?
4. Why are most houseflies able to survive the spraying of DDT?
5. Why is Darwin usually credited with first developing the concept of natural selection even though Wallace's published work preceded Darwin's?
6. Explain the two uses of the term *evolution*.
7. Describe the theory of evolution. What did Darwin contribute to this theory?
8. Explain why the concept of natural selection is valuable in many areas that have nothing to do with the theory of evolution?

ANALYSIS AND APPLICATION

1. Sometimes people say that an individual organism has developed a resistance to a poison or antibiotic. Why is that not likely? What does the person making such a statement probably mean?
2. Many people will notice a specialized adaptation of a plant or animal and will ask why such an adaptation should be present. How does the biologist phrase such a question?

been selectively spread through the population. Most were eaten by predators.

3. Because some had a body chemistry that somehow protected them against the DDT.
4. Because most houseflies today are descendants of the original few that had a natural resistance to DDT.
5. Darwin developed his ideas many years before he published them and many years before Wallace thought of them.
6. Evolution can refer to the process by which populations change and develop adaptations. Evolution can also refer to the theory of evolution.
7. It states that all organisms today have evolved from related organisms that lived in the past. Darwin contributed a great amount of evidence to support the theory.
8. It enables us to predict the effects of our attempts to eliminate populations of organisms that are considered pests.

ANSWERS TO ANALYSIS AND APPLICATION

1. Individuals rarely can develop traits that they were not born with. For example, the single bacterium probably does not develop a resistance to an antibiotic. It either has it or it does not. A person making such a statement probably means that the population rather than the individual has developed the resistance.
2. The biologist doesn't ask *why* in respect to an adaptation. The biologist phrases the question this way: What advantage did such an adaptation offer the plant or animal at the time it was being selected for survival within the population?

Investigation 24 from *Laboratory Investigations in Biology* can be done with this chapter.

11 *Early*



Humans

OBJECTIVES

- To describe the three species of *Australopithecus*
- To understand how anthropologists study fossil skulls
- To understand how *Homo erectus* was like and unlike modern humans
- To appreciate the advanced nature of the Neanderthals
- To understand scientific speculation and how it is used by scientists
- To describe the Cro-Magnon people

Early Humans

11-1 Human ancestors Who are the oldest ancestors of humans? When did they live? What were they like? Almost every person has wondered about those questions at one time or another. Those questions are also the main concern of **anthropologists** (an thrə pol'ə jists). Anthropologists specialize in the study of our human ancestors. This study includes structure and appearance of early humans, when and where they lived, and their general way of life. In this chapter, we shall try to summarize what anthropologists have discovered.

11-2 The earliest creatures In 1924 Raymond Dart, a South African anatomy professor, discovered an unusual skull. It was found in rock that was being mined in South Africa. Dart examined the skull and saw that it was unlike anything he had ever seen. It had humanlike features. But it also had characteristics that were unlike those of modern humans or human fossils that had been discovered up to that time. Dart decided that the skull was from a type of creature that had never before been described. He gave this new creature a name: ***Australopithecus africanus*** (ôz trə lō pith'ə kəs af rə kă'nəs) (abbr. *A. africanus*).

What features of the *A. africanus* skull were humanlike? It was from a creature that walked upright, on two legs. This was easy to determine by looking at the location of the **foramen magnum** (fə rā'mən mag'nəm). The foramen magnum is the opening where the spinal cord en-

MAIN IDEA

Anthropologists study our human ancestors.

This is the skull of *A. africanus* that was discovered by Raymond Dart in 1924. Professor Dart called the creature the Taungs' child.

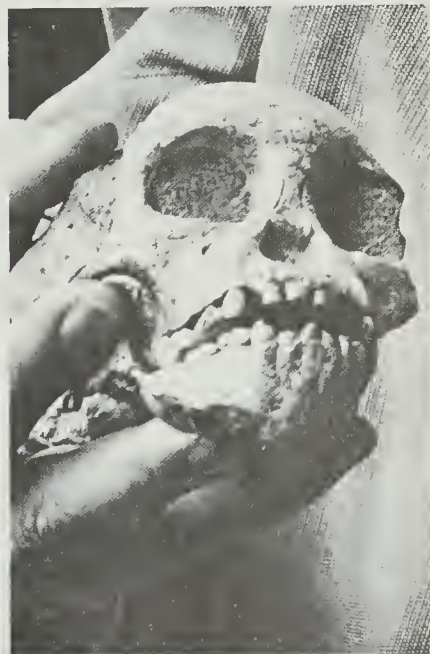


FIGURE 11-1

The jaw of an ape (left) is U-shaped. A human jaw (right) is bow-shaped. The jaw of *A. africanus* was similar to a human jaw.

SCIENCE BACKGROUND

Most evidence of human ancestors has come from fossils that were dug up and studied by paleoanthropologists.

MAIN IDEA

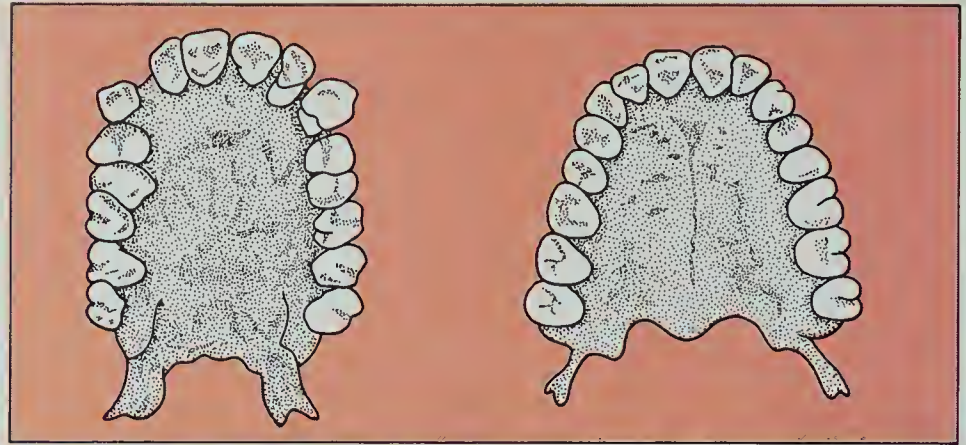
From a skull that was discovered in South Africa, Raymond Dart decided that a new group of humanlike creatures had existed. He named the creature *A. africanus*. The location of the foramen magnum showed that it walked upright. The jaw and teeth arrangement followed human patterns.

MAIN IDEA

A. africanus was small and ate meat. *A. robustus* and *A. boisei* were larger and had adaptations for eating vegetation. Our relation, if any, to these early humans is unclear.

SCIENCE BACKGROUND

There is some doubt that *Australopithecus boisei* should be considered a separate species. There is another hypothesis that it is just a variety of *A. robustus*.



ters the skull. In humans, as in *Australopithecus*, the foramen magnum is underneath the skull and the head sits over the top of the spine. Animals that walk on four legs have the foramen magnum at the back of the skull.

Other humanlike characteristics included the shape of the teeth and the way they were arranged in the jaws. In animals such as gorillas and chimpanzees the teeth are arranged in an upside-down U shape, with the back teeth nearly parallel. Humans have their teeth arranged more like an upside-down dish, with the back teeth farther apart than the others. This was the arrangement in *A. africanus*. Another difference was in the spacing between the front and back teeth. Chimpanzees and related animals have spaces where the large canine teeth can fit when the mouth is closed. There are no such spaces between the teeth in humans nor were there any in *A. africanus*.

11-3 More specimens of *Australopithecus*

Since 1924 several other types of *Australopithecus* have been discovered. It is now possible to make some general statements about their size, when they lived, and how they might have behaved.

A. africanus was less than 1.5 m tall and weighed between 36 and 45 kg. Evidence indicates that *A. africanus* was a hunter of animals and lived mostly on a diet of meat. It may have lived from 5 to 5.5 million years ago.

After the discovery of *A. africanus*, fossils of two more related creatures were discovered. One, called ***Australopithecus robustus*** (rō bus'təs), was larger than *A. africanus*. *A. robustus* weighed about 65 kg. Its teeth were larger than those of *A. africanus* and were adapted to the grinding of vegetable food. Also the skull of *A. robustus* had a ridge down the middle, like that of a gorilla or a chimpanzee. Such a ridge allowed more room for the attachment of powerful jaw muscles needed to chew vegetation.

The other creature was called ***Australopithecus boisei*** (bwä'sē). It was even larger and more robust than *A. robustus*. *A. boisei* had large back teeth and a very heavy jaw. This indicates that it, too, was a vegetable eater.

At present there is no widely accepted theory on how the three kinds of *Australopithecus* relate to the development of humans. There are several hypotheses, but no one hypothesis is favored by a majority of anthropologists. However, most believe that *A. robustus* and *A. boisei* became extinct.

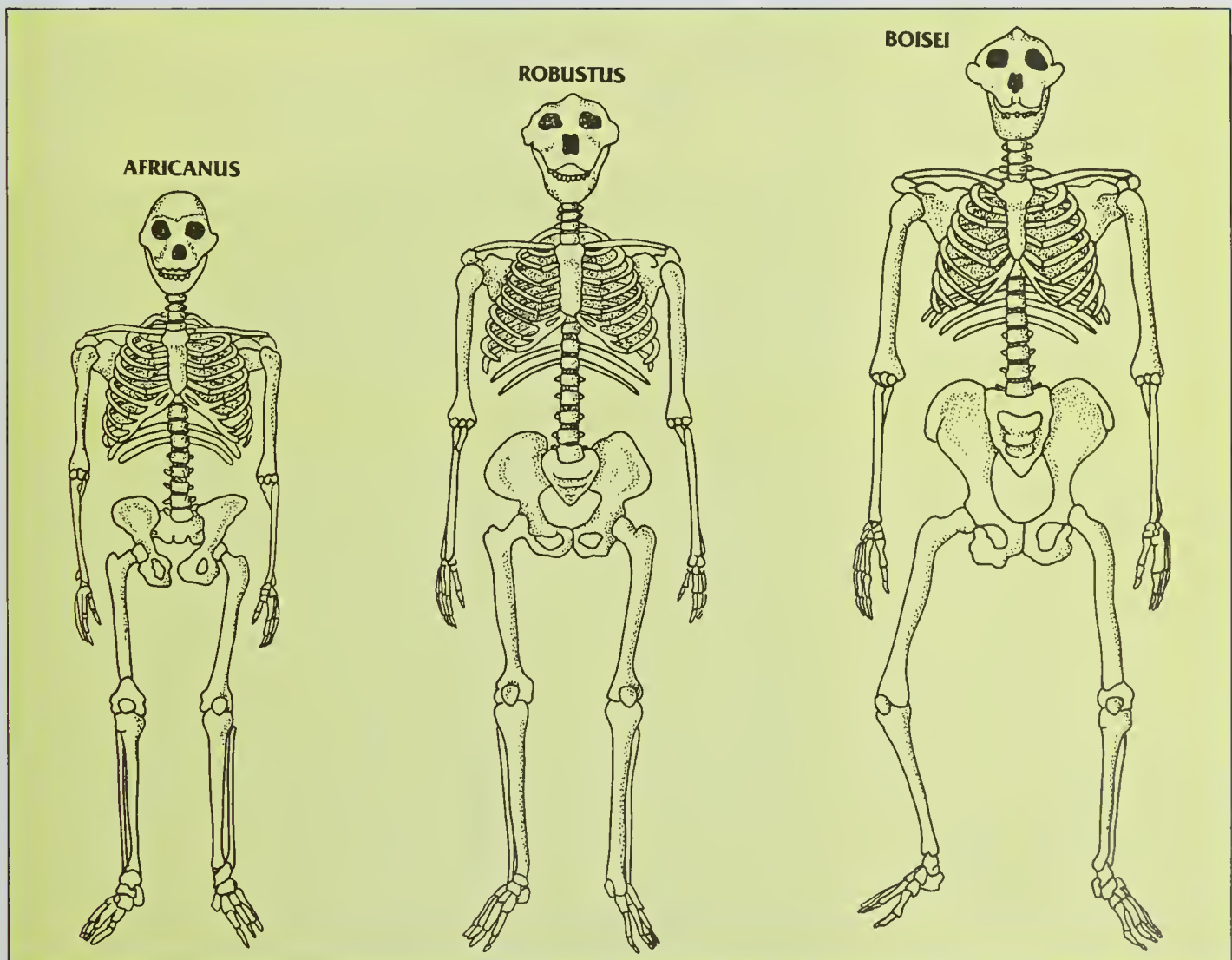
11-4 *Homo erectus* Anthropologists consider the first true human to be ***Homo erectus*** (hō'mō i rek'təs). The name means "upright man." Many *Homo erectus* fossils have been found, along with tools and other evidence of this early human's activities. The Java man, Heidelberg

MAIN IDEA

Homo erectus was taller and probably more intelligent than *A. africanus*. The more primitive head structure is the major difference between *Homo erectus* and the modern human. *H. erectus* used fire for several purposes.

FIGURE 11-2

The skeletons of *A. africanus* (left), *A. robustus* (middle), and *A. boisei* (right) are shown in the figure below.



SCIENCE BACKGROUND

Highly recommended for its exceptionally good description of *Homo erectus* is *The First Men* by Edmund White, in *The Emergence of Man Series* (New York: Time-Life Books, 1973). There is a very good description of the work of Eugène Dubois and Davidson Black who discovered Java man and Peking man, respectively. These accounts would make interesting reading for many students.

man, and Peking man are older names for the first-discovered *Homo erectus* fossils. The oldest fossils date back 1.3 million years. However, it is believed that *Homo erectus* became widespread over Africa, Asia, and Europe about 800 000 years ago.

Homo erectus fossils indicate that these people were much advanced over *A. africanus*. They were taller, standing about 1.7 m. The brain of *Homo erectus*, on the average, was almost twice as large as that of *A. africanus*. In fact, the average brain size of *Homo erectus* was within the size range of a modern human's brain. A larger brain does not necessarily mean greater intelligence. But it is considered to be a good indication of intelligence. A comparison suggests that *Homo erectus* was much more intelligent than *A. africanus*.

The skull is the area that clearly shows differences between *Homo erectus* and a modern human. In *Homo erectus* the forehead sloped backward at the top. The bone above the eyes, where the eyebrows were located, was thick and stuck out over the eyes. The lower jaw was large and heavy, with almost no chin.

To see the other differences between the bones of *Homo erectus* and a modern human requires a skilled anatomist.

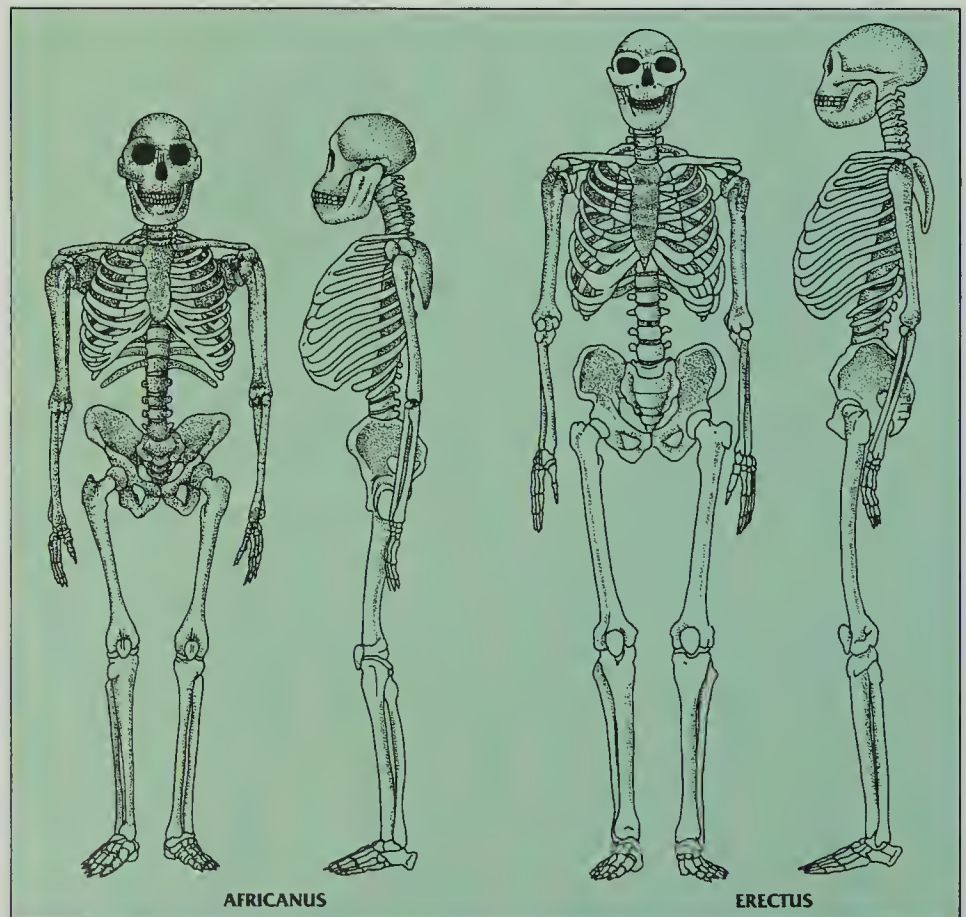


FIGURE 11-3

The greater spinal curvature in the skeleton of *H. erectus* (right) probably meant a more erect posture and more efficient walking ability than in *A. africanus*.

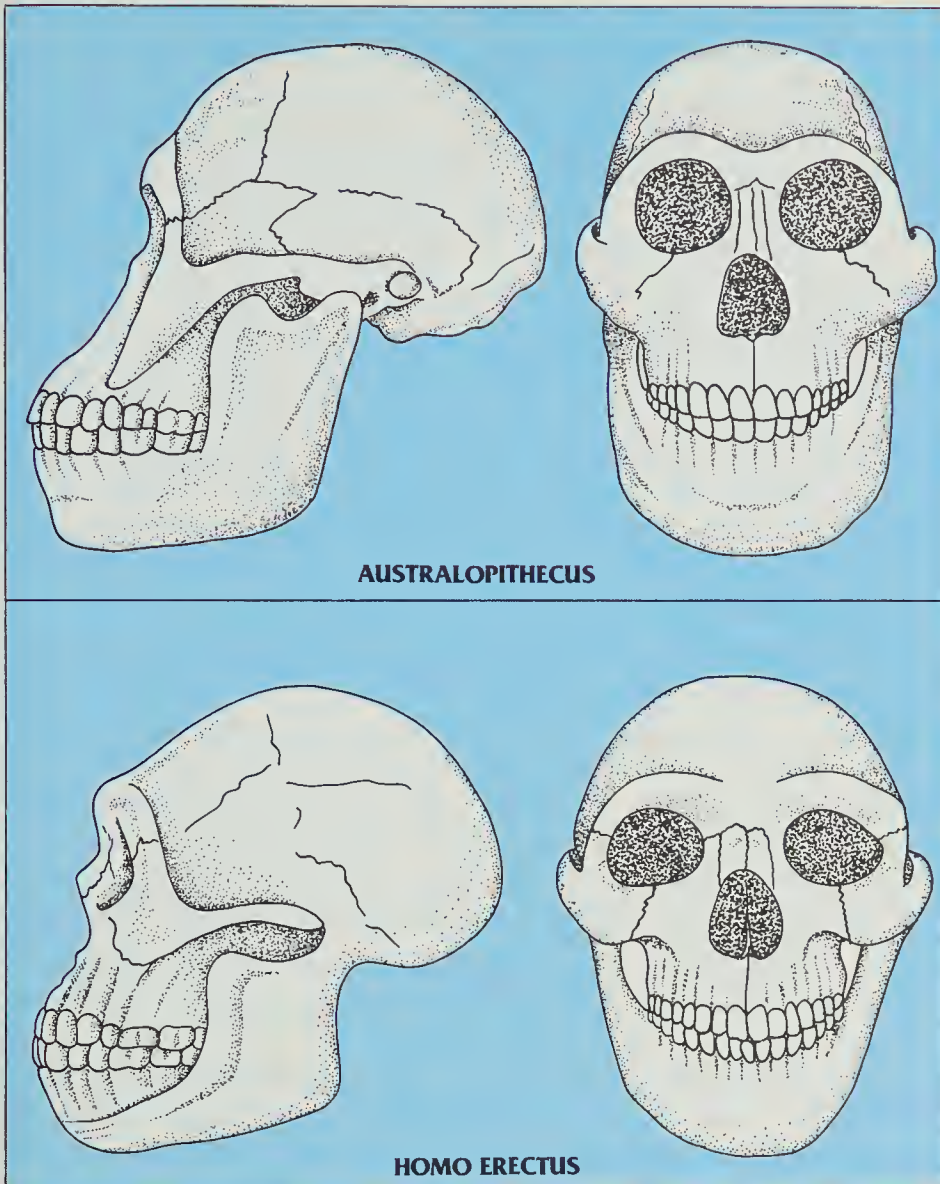


FIGURE 11-4

The skulls of *A. africanus* (top) and *H. erectus* are shown in this figure. *H. erectus* had a brain twice as large as that of *A. africanus*.

Mainly the bones of *Homo erectus* were thicker and heavier. Probably the individuals themselves had more heavily muscled arms and legs than the average human of today.

One major advancement that scientists believe occurred about 750 000 years ago was the use of fire by *Homo erectus*. In former living sites such as caves, where fossils of these people are often found, there is usually carbon and charcoal left from their fires. At one site in China, the charcoal was about 6.5 m deep. This suggests that the people always kept a fire burning. Fire would have enabled them to survive freezing and subfreezing temperatures. Also, fire could have been used to cook food. Cooking would have made plant material much easier to chew and digest. It could have made all the food taste better. Fire might also have been used during the hunting process. Most animals are extremely afraid of fire and always run

away from it. There is evidence that *Homo erectus* used fire to stampede animals over cliffs or into traps.

MAIN IDEA

Neanderthals resembled both *H. erectus* and modern humans. They were probably intelligent and showed imagination and caring for others.

SCIENCE BACKGROUND

Another excellent book for background reading is *The Neanderthals* by George Constable, in *The Emergence of Man Series* (New York: Time-Life Books, 1973).

Besides the evidence that Neanderthals had imagination and humanlike feelings, there is also evidence that they may have practiced cannibalism. Skulls have been found with the foramen magnums (magna) widened, possibly for scooping out the brains that would be eaten. Such a practice has been observed among cannibals of more recent times.

SCIENCE BACKGROUND

The Neanderthals are often given the scientific name *Homo sapiens neanderthalensis*, while Cro-Magnons are *Homo sapiens sapiens*, which is sometimes used as our own complete name. The oldest Cro-Magnon fossil with a date that anthropologists are sure about is from Czechoslovakia. It dates back about 26 000 years.

MAIN IDEA

The Neanderthals mysteriously disappeared. Some speculate that they were somehow wiped out. Others think they evolved into modern humans.

11–5 The Neanderthals About 100 000 years ago, another group of humans were present on the earth. They were the **Neanderthal** (nē an'der täl) people, named after a valley in Germany where their fossils were first found.

The term *Neanderthal* is often used to describe a crude person. Cartoons often show “Neanderthals,” picturing them as brutes who live in caves, carry clubs, and drag women around by their hair. Such opinions of the Neanderthals are based largely upon older research and ideas of anthropologists. For many years the Neanderthals were thought to be brutes of low intelligence and with crude, animallike behavior.

Anthropologists of today have more respect for the Neanderthal people. In fact, they give Neanderthals and modern humans the same scientific name: *Homo sapiens* (sā'pē ənz). The Neanderthals were different from us mainly in the shape of their heads and in facial features. Their foreheads were sloped, and they had large brows. Their lower jaws were heavy and nearly chinless. In general, their heads and facial features were rather similar to those of *Homo erectus*. But there was one major difference. The Neanderthal brain was larger, about the same size as that of a modern human.

The Neanderthal people were widely spread over Europe, Africa, and Asia. They were adaptable enough to survive several ice ages. Also they were good toolmakers, and many of their stone axes and scrapers have been found with their fossil bones. Many Neanderthals lived in caves, and there is evidence that they may have made crude shelters out of animal skins.

11–6 A mystery About 40 000 years ago something happened to the Neanderthals. Fossils of more recent Neanderthals have not been discovered. This has led to what anthropologists call the “Neanderthal problem.” There is no single hypothesis on the disappearance of the Neanderthals that has much evidence to support it.

In the absence of evidence, the scientist often develops speculation which is a guess that has some basis in fact. Speculation is definitely not the type of information to be taken seriously. It is the scientist's way of making predictions that might be useful for further study.

There is much speculation about the Neanderthal problem. One idea is that the people were trapped in northern

regions by advancing glaciers. Another is that they were wiped out by some kind of disease epidemic for which they had no natural immunity. Still another is that they were wiped out by a new, modern type of human that replaced them.

11-7 The Cro-Magnons Between 30 000 and 40 000 years ago, a modern type of human first appeared. This type of human was named **Cro-Magnon** (krō mag'non), after the place in France where it was first discovered. The Cro-Magnons were much taller and more erect than the Neanderthals. They had vertical foreheads with almost no browridges. Their faces were vertical on the sides and with a prominent chin.

The Cro-Magnons were advanced over the Neanderthals in many ways. They made very fine stone weapons and tools. They used clay to make pottery. Their burial procedures were much more elaborate. Some skeletons have been found with primitive jewelry.

Probably the most remarkable product of the Cro-Magnons is their art. In several caves in Europe, there are color paintings that were made by these people. The paintings are mostly of animals, and they are usually in deep regions of the caves, where people would not have lived. They were probably not decorations but may have served some spiritual purpose. The paintings show many animals that were hunted for food, so perhaps they were shrines that the people visited before the hunt.

SCIENCE TERMS

anthropologists
Australopithecus africanus
foramen magnum
Australopithecus robustus
Australopithecus boisei
Homo erectus
Neanderthal
Homo sapiens
speculation
Cro-Magnon
Tasaday

MAIN IDEA

The Cro-Magnons had a modern-type appearance. They made fine tools and pottery. They also produced art.

The cave art of the Cro-Magnons indicates that these first modern humans had a fairly advanced culture.



Anthropologists often study present-day primitive societies to help them understand how our ancestors may have lived.

MAIN IDEA

Besides studying fossils, anthropologists also study our present primitive societies. By studying groups like the Tasaday, they hope to find clues about our early ancestors.

ANSWERS TO CHECK YOUR FACTS

1. Scientists who study fossils of our human ancestors.
2. Because the foramen magnum is located underneath the skull.
3. The jaw is rounded with the back teeth farthest apart, and the teeth have no space for a large canine tooth. These traits are seen in humans but not in chimpanzees.

ANSWERS TO REVIEW QUESTIONS

1. It was larger and had larger teeth. It had a ridge on the skull to allow large jaw muscles to attach. It ate vegetation.
2. About 800 000 years ago. They had a much larger brain and were probably more intelligent.
3. *Homo erectus* had heavier bones, a sloping forehead, a heavy lower jaw with almost no chip, and the skull stuck out above the eyes.
4. To keep warm, cook food, and to drive prey over cliffs or into traps.
5. They had a large brain. They



11–8 Another type of study Up to now, the evidence we have discussed concerning primitive humans and humanlike creatures has been based upon fossils. But this is not the only approach used by anthropologists. Another method is to study primitive people who are living today or who have lived in the recent past.

Within the past 100 years, many primitive societies have been studied. The native North and South Americans have a variety of tribes with primitive characteristics. The Amazon River region of South America still has a few societies that live much as they did in the past. Some parts of Africa, the East Indies, and Australia also have peoples who only recently have come in contact with modern humans.

Probably the most unusual group of people living today is a small band that was first visited by anthropologists in 1971. They are the **Tasaday** (tô sô dĩ'). They live in the Philippines, and there are only about 25 in their band. What is so unusual is that they have always lived in complete isolation from modern humans. They live in a cave. They make and use stone tools. They hunt with primitive weapons and fish with their hands. They make fire by twirling a round stick in a wooden base. By studying the Tasaday, anthropologists feel they are seeing how our ancestors might have lived thousands of years ago.

CHECK YOUR FACTS

1. What are anthropologists?
2. How do we know that *A. africanus* walked upright?
3. In what ways were the jaws and teeth of *A. africanus* more like those of modern humans than they were like those of chimpanzees?

SUMMARY

Anthropologists try to unravel the mysteries surrounding the earliest ancestors of modern humans. *Australopithecus africanus* was very primitive but had many humanlike traits. It walked upright and made crude tools. The related creatures *A. robustus* and *A. boisei* were adapted to eat vegetation; *A. africanus* ate meat. Anthropologists are not sure whether *Australopithecus* is related to modern humans.

Homo erectus had a large brain and used fire. *Homo erectus*, it is believed, became widespread about 800 000 years ago.

Though commonly considered to be stupid brutes, the Neanderthals were probably quite intelligent. They cared for others and performed burial ceremonies. They survived through several ice ages—a sign that they were adaptable. About 40 000 years ago, the Neanderthals vanished.

REVIEW QUESTIONS

1. How was *A. robustus* different from *A. africanus*?
2. When did *Homo erectus* become widespread? How were they advanced over *A. africanus*?
3. What are some anatomical differences between *Homo erectus* and modern humans?
4. How might *Homo erectus* have used fire?
5. What evidence exists to indicate that Neanderthals were not stupid brutes?
6. What is meant by the “Neanderthal problem”? What might have happened?
7. What is considered to be the most remarkable product of the Cro-Magnons?
8. Why are anthropologists studying the Tasaday?

ANALYSIS AND APPLICATION

1. Suppose that you and a friend find a skull while digging in a hillside. After examining the skull, you think that it is the skull of an ape. However, your friend feels that it is the skull of a human. What features of the skull could be used to determine who is correct?
2. An anthropologist finds a humanlike skull while on a dig in Asia. The skull is determined to be that of an individual of the *Homo erectus* type. How would this skull differ from the skull of a modern human?
3. Apparently there were at least three different species of *Australopithecus* living in Africa around the same time. How do scientists know that two of these were basically plant eaters?

survived several ice ages. They made good tools. They imagined an afterlife and had burial ceremonies. They cared for other individuals.

6. The fossil record of Neanderthals suddenly stops at about 40 000 years ago. The “Neanderthal problem” refers to the mystery surrounding their disappearance. Glaciers, disease, or more modern humans may have eliminated them. They may have evolved into or intermarried with modern-type humans.

7. Their art.

8. Because their isolation from the rest of the world has resulted in a primitive culture that may be similar to that of early humans.

ANSWERS TO ANALYSIS AND APPLICATION

1. In an ape skull, the foramen magnum would be more toward the back of the skull, the back teeth would be large and flattened, and there would be large canines.
2. The forehead would slope backwards, the bones above the eyes would be thick and protruding, and there would be almost no chin.
3. By studying the teeth.

Investigation 25 from *Laboratory Investigations in Biology* can be done with this chapter.

12

Classification



of Life

OBJECTIVES

- To appreciate the need for classifying organisms
- To understand how organisms are classified
- To realize that body structure is the main kind of evidence used in classification
- To understand the definition of a species
- To know the classification hierarchy of categories in proper order
- To explain what makes up a scientific name
- To appreciate the advantage of scientific names over common names
- To describe some taxonomic problems

12-1 The need for classification Can you imagine going to a library where 2 million books are on the shelves, but in no special order? To find one specific book you might spend weeks or even months. However, we do not have that problem when we go to a library. The books are classified into a system that we can understand and use. This system classifies books that are similar into groups—fiction, nonfiction, travel, history, aircraft, and so on. Out of 2 million books, we should be able to find any specific book within a few minutes.

No biologist knows exactly how many different kinds of organisms have been identified. Estimates begin at about 2 million and range upward. Describing and studying this many different organisms would be impossible without some means of classification. This need for classification was recognized many centuries ago. Organisms were classified into broad categories, such as plants, animals, trees, worms, birds, snakes, and grasses. Over the years the system of classification has evolved to fit all the newly discovered organisms. They are now classified according to a basic method that is recognized by all biologists of the world. This method, and the ideas that it is based upon, will be discussed in this chapter.

12-2 The basis for classification Organisms are classified on the basis of their relationships to each other. In turn, these relationships are based upon evidence of common ancestors and their theoretical evolution. In other words, organisms are classified according to their theoretical evolutionary relationships to each other.

MAIN IDEA

All organisms are classified according to a basic method recognized by all biologists. That method is necessary for describing and studying the many different organisms.

SCIENCE BACKGROUND

To introduce this chapter, bring to class a jar containing a mixture of bolts, nuts, washers, screws, nails, and so on. Have the students classify them into groups. Typically they will put all the bolts into one pile, and so on. Have them continue the classification, putting round-headed screws into one group and flat-headed screws into another, and so on.

MAIN IDEA

Taxonomists classify organisms according to their theoretical evolutionary relationships to other organisms. Body structure is commonly used to classify organisms but is not sufficient in many cases.



While several species of thrushes are very similar in appearance, their songs are quite distinct and often serve to identify them accurately.

SCIENCE BACKGROUND

Besides behavior, biochemical differences are becoming more and more useful in detecting theoretical evolutionary relationships. For example, studies on the primary structure (amino acid sequence) of insulin is giving taxonomists further evidence in developing relationships between various primates.

MAIN IDEA

A species is one or more groups of interbreeding natural populations that are reproductively isolated from other such groups.

A group of related organisms can be classified in a category called a **taxon** (tak'sən) (pl. *taxa*). Biologists who specialize in classifying organisms are called **taxonomists** (tak son'ə mists).

Taxonomists use a variety of evidence in classifying organisms into taxa. Body structure is the most commonly used type of evidence. For example, all animals with feathers fit into one taxon—the birds—while all animals with hair fit into another—the mammals.

For many organisms, body structure alone is not sufficient evidence for classification. In eastern North America, for example, there are four thrushes (a type of bird) that are similar in appearance. Experts are sometimes confused when they try to identify them. However, the four thrushes have very different songs, and they also differ in their food-gathering habits. Therefore differences in behavior are another kind of evidence that is used in the classification process.

12-3 The concept of species Up to now we have said that there are different kinds of organisms. Now we must be more precise. We must substitute the term *species* for *kind*. In general, a species includes just one kind of organism. But there is a more precise definition, and it requires some explanation.

First, we must review the concept of the **population**. A population is a group of organisms of one kind, defined in space and time. This could be the population of red squirrels in Banff National Park, Alberta, in June.

Second, we must explain what is meant by a **natural population**. This is a population that interbreeds *in nature* and is not controlled by humans. A population of peacocks in St. George's Island Zoological Gardens in Calgary is *not* a natural population.

Third, we must introduce the concept of **reproductive isolation** (rē prə duk'tiv ī sə lā'shən). A reproductively isolated organism is one that is prevented from breeding with another organism by some mechanism. This mechanism might be a difference in reproductive organs or a difference in reproductive behavior. Or the isolation could occur at the cellular level. The sperm and egg might not fuse, or a fertilized egg might not divide.

Now we can define a species. A **species** (spē'shēz) is one or more groups of interbreeding natural populations that are reproductively isolated from other such groups. A natural population of red squirrels in Banff National Park, Alberta, may belong to the same species as a population of red squirrels in Whiteshell Provincial Park, Manitoba. If they can interbreed but are reproductively isolated from other squirrels, by definition they are of the same species.

SCIENCE BACKGROUND

The species definition given in the text is probably the most acceptable definition and comes from Ernst Mayr, a recognized world authority. However, there are problems with the definition. One problem relates to uniparental (asexual) reproduction, where the "interbreeding" part of the definition is meaningless. Fortunately such populations usually have distinct genetic discontinuities that, in turn, create distinct morphological differences that serve to delimit species. The species definition also is a problem in some plant families because of extensive hybridization between related plants.



The mule deer, Odocoileus hemionus (top), and the white-tailed deer, Odocoileus virginiana (bottom), are closely related species. Although their ranges overlap, the white-tailed deer is found in North America from the east to the Rocky Mountains, while the mule deer is found from the Rocky Mountains to the Pacific coast.



WESTERN WHITE PINE

CLASSIFICATION KEY

To identify the leaves shown on these pages, use the Classification Key. The key consists of a series of paired statements. To identify a leaf, decide which statement in the first pair accurately describes that leaf. Go to the pair of statements indicated by the number following your choice. Again decide which statement describes the leaf. If the statement is followed by the name of a plant, you have identified the leaf. If the statement is followed by a number, go to that pair of statements to make another choice. Continue the process until you have identified the leaf. Using the key, all of the leaves can be identified.

1. Leaf compound, consisting of three or more leaflets _____ **2**

1. Leaf not compound _____ **3**

2. Leaf with five leaflets; fruit, a pair of winged seeds _____ **box elder *Acer negundo***

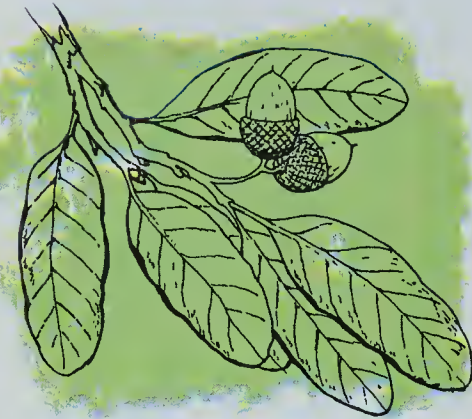
2. Leaf with more than five leaflets; fruit, a nut _____ **black walnut *Juglans nigra***

3. Leaf needlelike _____ **4**

3. Leaf not needlelike _____ **7**

4. Needles in bundles of two or three _____ **5**

4. Needles not in bundles _____ **6**



LIVE OAK



CATALPA



BOX ELDER



EASTERN RED CEDAR



DOUGLAS FIR

5. Needles in bundle of three _____
_____ **loblolly pine** *Pinus taeda*

5. Needles in bundle of five _____
_____ **western white pine** *Pinus monticola*

6. Needles arranged around stem, cone scales open
_____ **Douglas fir** *Pseudotsuga taxifolia*

6. Needles arranged around stem, cone scales
closed _____ **white fir** *Abies concolor*

7. Leaf scalelike and covering stem _____
_____ **eastern red cedar** *Juniperus virginiana*

7. Leaf flat, not scalelike _____ **8**

8. Leaf edge smooth _____ **9**

8. Leaf edge not smooth _____ **10**

9. Fruit, a long pod _____
_____ **northern catalpa** *Catalpa speciosa*

9. Fruit, an acorn _____
_____ **live oak** *Quercus virginiana*

10. Leaf edge like a saw blade; fruit, a winged seed
_____ **American elm** *Ulmus americana*

10. Leaf edge with sharp points and rounded in-
dentations; fruit, an acorn _____
_____ **pin oak** *Quercus palustris*



BLACK WALNUT



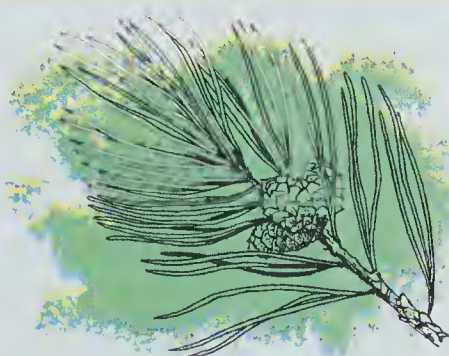
WHITE FIR



PIN OAK



AMERICAN ELM



LOBLOLLY PINE

Table 12–1 Classification of Four Organisms

	<i>Human</i>	<i>Dog</i>	<i>Honeybee</i>	<i>Live Oak</i>
Kingdom	Animalia	Animalia	Animalia	Plantae
Phylum (or Division)	Chordata	Chordata	Arthropoda	Tracheophyta
Class	Mammalia	Mammalia	Insecta	Angiospermae
Order	Primate	Carnivora	Hymenoptera	Fagales
Family	Hominidae	Canidae	Apidae	Fagaceae
Genus	<i>Homo</i>	<i>Canis</i>	<i>Apis</i>	<i>Quercus</i>
Species	<i>sapiens</i>	<i>familiaris</i>	<i>mellifera</i>	<i>virginiana</i>

MAIN IDEA

The categories, in descending order, are kingdom, phylum, class, order, family, genus, and species.

SCIENCE BACKGROUND

Not mentioned in the text is the use of subcategories and supercategories, such as the subphylum or superfamily, which are intermediate categories.

To familiarize students with the classification category hierarchy, it is suggested that they pick a well-known organism, such as a mammal or bird, and research its complete classification.

MAIN IDEA

The scientific name consists of the genus name and the specific name. The specific name is always given a Latin ending.

12–4 The major categories In the 1700s a Swedish botanist named Carolus Linnaeus devised a series of classification categories. Since then his categories have been modified and adopted by taxonomists. These categories are arranged in a hierarchy, which is a series of levels of increasing number or complexity.

The highest category, which contains the largest number of organisms, is the **kingdom**. All plants belong to the kingdom Plantae. All animals belong to the kingdom Animalia. We shall have more to say about kingdoms later.

Below the kingdom is the **phylum** (fī'ləm) (pl. *phyla*), although many botanists prefer to use the term **division** for this level of classification. Each kingdom is made up of several phyla, or divisions.

The next categories, in sequence below the phylum, or division, are the **class**, **order**, **family**, **genus** (jē'nus), and **species**. In Table 12–1 you can see how four organisms are classified in all the different categories.

12–5 The scientific name Linnaeus also established a procedure for naming organisms. Each organism is given a **scientific name**, which consists of two Latin words. The first word is the name of the genus to which the organism belongs. The second word is the name of the species. The scientific name is the most specific identification of an organism. For example, the scientific name of



In different parts of North America, *Felis concolor* (above) is called a cougar, a puma, or a mountain lion.

SCIENCE TERMS

taxon
taxonomists
population
natural population
reproductive isolation
species
kingdom
phylum
division
class
order
family
genus
scientific name

SCIENCE BACKGROUND

As a research assignment, students could be required to look up the scientific names of all the trees that are on the school ground. Using dictionaries they can often find words similar to the specific names and decide why such names were selected. For example, two maple trees, *Acer saccharinum* and *Acer saccharum* can be researched in *The American Heritage Dictionary*, where the term *saccharo* is explained as "indicating sugar" and the Latin root word *saccharum* (sugar) can be found. Another maple, *Acer rubrum*, can be found under the closely related word *ruby*, where the Latin root word for red, *rubeus*, can be found.

the common house cat is *Felis catus*. *Felis* is the genus to which the house cat belongs; *catus* is its species name. A closely related cat is the cougar. The scientific name of the cougar is *Felis concolor*.

It is common practice to underline or italicize scientific names. Also, the Latin names of all categories other than species are capitalized.

A species name may reflect the location where an organism is found, or it may describe a physical feature of the organism. Some organisms are named for people. For example, the aquatic, or water, buttercup is named *Ranunculus aquatilis*. The wild iris, named after Missouri, is *Iris missouriensis*. Sagebrush has three toothlike structures on the ends of its leaves. Its scientific name is *Artemesia tridentata*, and the species name means "three teeth." The syringa, or mock orange, is named after Meriwether Lewis of the Lewis and Clark expedition. Its scientific name is *Philadelphus lewisii*.

12-6 The advantage of scientific names

Scientific names often seem strange or difficult to beginning students of biology. But they have one important advantage over common names for which there are no standards. The advantage of the scientific name is that it remains the same in all countries of the world.

MAIN IDEA

Scientific names provide a common language for biologists all over the world.

Table 12–2**Eleven Common Names for Dog**

French	chien
German	Hund
Italian	cane
Spanish	perro
Polish	pies
Russian	sabaka
Dutch	hond
Hebrew	kelev
Japanese	inu
Hindi	kutha
Basque	Txakurra

Let us use the example of the word *dog*, shown in Table 12–2, to explain the advantage of scientific names. The common name *dog* is used to describe a specific kind of animal in English-speaking countries. In France the same animal is called a *chien*; in Germany, a *Hund*; and in Russia, a *sabaka*. Yet in all these countries anyone could speak of this animal by calling it *Canis familiaris*, its scientific name.

12–7 Taxonomic problems One problem of the taxonomist is that no single person can be an authority except on relatively small groups of organisms. A good taxonomist, after spending a lifetime studying a special group, might recognize from 2 000 to 3 000 species on sight. But that is only a tiny fraction of all the living organisms.

Another problem has to do with classifying organisms into different categories. Dividing up all the earth's organisms into kingdoms is an example of such a problem. Years ago the problem did not exist. Everything was either a plant or an animal, so taxonomists divided all organisms into two kingdoms. Then, after the discovery of microorganisms, a new problem arose. Some microorganisms acted like animals because they swam around in the water and fed on other organisms. Others had chloroplasts and made their own food, like plants. But many microorganisms were like the single-celled organism called *Euglena* (yü glē'nə). *Euglena* swims like an animal but has chloroplasts and makes its own food.

To solve this problem, a third kingdom was proposed for the microorganisms—kingdom Protista. This kingdom was generally accepted until studies with the electron microscope showed major differences in cells. Certain cells, the procaryotic cells, do not have nuclei or other membrane-enclosed organelles. The bacteria and blue-green algae are made up of procaryotic cells. Therefore a new kingdom was proposed for the bacteria and blue-green algae. This is the kingdom Monera. Many biologists now feel that there is more difference between the monerans and protists than between plants and animals.

In recent years a number of biologists have suggested that there should be a fifth kingdom—kingdom Fungi (fun'jə). It is possible that the five-kingdom classification system will change as new information is discovered about organisms.

ANSWERS TO CHECK YOUR FACTS

1. Because there are so many organisms that describing and studying them would be impossible without a system to classify them.
2. Theoretical evolutionary relationships to other organisms.
3. Groups of organisms unique enough to be classified into separate categories. They specialize in classifying organisms.

CHECK YOUR FACTS

1. Why is classification necessary?
2. What is the main basis for classification?
3. What are taxa? What do taxonomists do?

SUMMARY

To describe and study the many types of organisms, it is necessary to classify them. All organisms are classified according to a basic method that is recognized by biologists all over the world. They are classified according to their theoretical evolutionary relationship to other organisms. Body structure is common evidence used to classify organisms, but it alone is not sufficient in many cases. Biologists who specialize in classifying organisms are called taxonomists. A population is a group of organisms of one kind, defined in space and time.

REVIEW QUESTIONS

1. What is a population? When is a population considered natural?
2. Explain reproductive isolation. Name some mechanisms of reproductive isolation.
3. Define a species.
4. Name two contributions that Linnaeus made to taxonomy.
5. Name the major categories, in sequence, above the species.
6. What are the two parts of the scientific name? Why are these names useful to biologists?
7. Why was kingdom Protista formed? Why was kingdom Monera proposed not long after that?

ANALYSIS AND APPLICATION

Listed below are ten scientific names and opposite them are ten common names. Use a dictionary to find clues that will help you match each scientific name with the correct common name. List the root words and clues used to make your decisions.

- | | |
|---------------------------------------|-------------------------|
| 1. <i>Cleome lutea</i> | A. two-spotted lady- |
| 2. <i>Trifolium macrocephalum</i> | bird beetle |
| 3. <i>Adalia bipunctata</i> | B. sunflower |
| 4. <i>Hydrophyllum caputum</i> | C. round bluebell |
| 5. <i>Sarcophagus haemorrhoidalis</i> | D. flesh fly that bites |
| 6. <i>Helianthus annuus</i> | and brings blood |
| 7. <i>Musca domestica</i> | to surface |
| 8. <i>Campanula rotundifolia</i> | E. common bull |
| 9. <i>Cirsium vulgare</i> | thistle |
| 10. <i>Allium cernuum</i> | F. housefly |
| | G. waterleaf |
| | H. bighead clover |
| | I. yellow bee plant |
| | J. nodding onion |

ANSWERS TO REVIEW QUESTIONS

1. A group of organisms of one kind, defined in space and time. When not controlled by humans.
2. A reproductively isolated organism is one that is prevented from breeding with another organism. Such mechanisms are different reproductive organs, different behavior.
3. A species is one or more groups of interbreeding natural populations reproductively isolated from other such groups.
4. Classification categories; the two-part scientific name.
5. Genus, family, order, class, phylum (division), kingdom.
6. The genus name and the specific name. They allow biologists to name organisms in a common language.
7. Because some microorganisms resemble both plants and animals. Because procaryotic cells are different from eucaryotic cells.

ANSWERS TO ANALYSIS AND APPLICATION

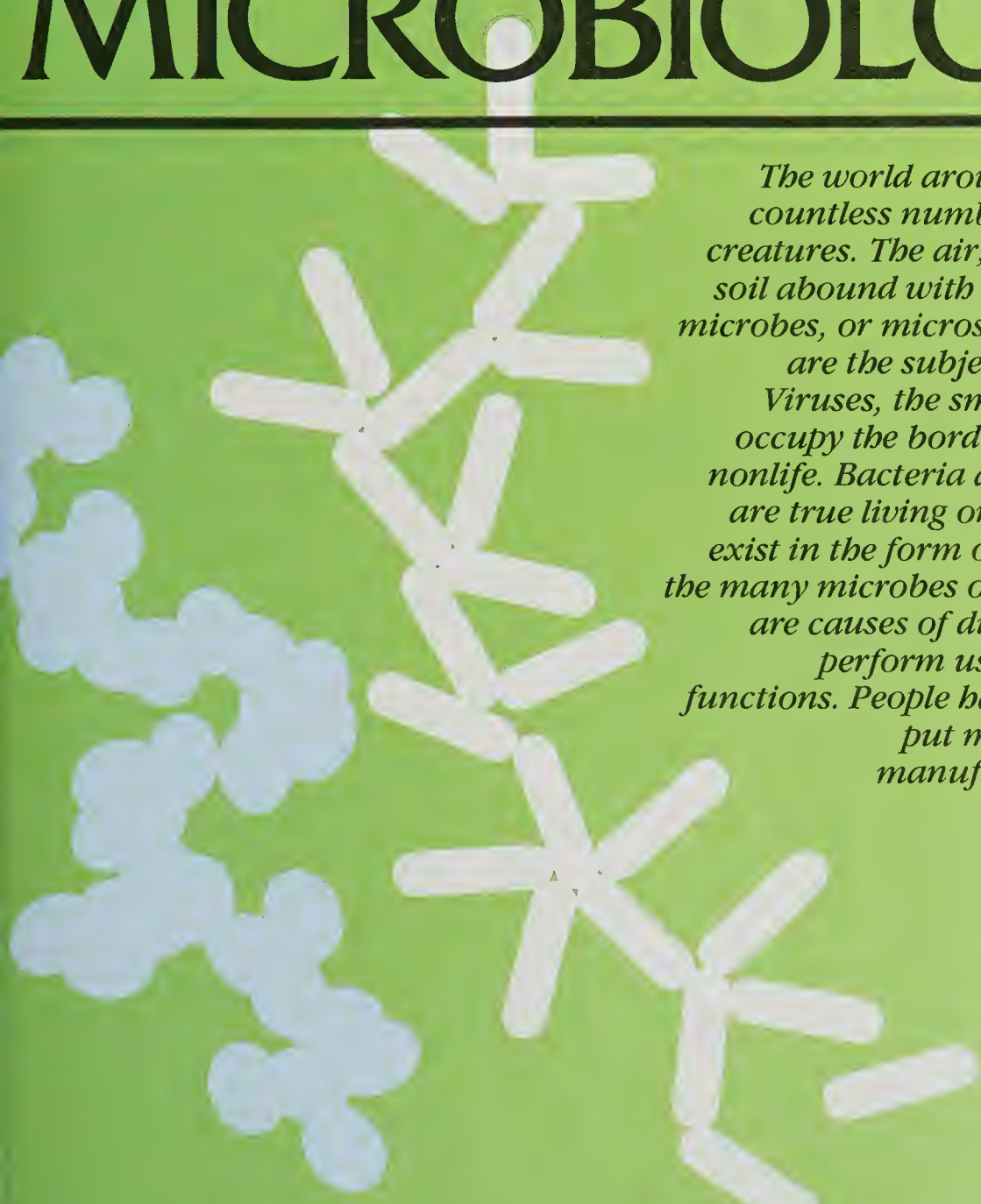
1. I Clue: L. *luteus*, yellow
2. H Clue: Gr. *makros*, large; L. *cephalous*, head
3. A Clue: L. *bi-*, two; L. *punctate*, marked or spotted
4. G Clue: Gr. *hudōr*, water; L. *phyllus*, leaf
5. D Clue: L. *sarcophagus*, flesh-eating; L. *haemorrhoida*, liable to discharge blood
6. B Clue: L. *heliacus*, the sun
7. F Clue: L. *Musca*, the fly; L. *domesticus*, house
8. C Clue: L. *campana*, bell; L. *rotundus*, round
9. E Clue: L. *vulgaris*, common
10. J Clue: L. *cernuus*, nodding (perhaps also relationship between L. *Allium*, garlic)

UNIT 2 REVIEW

1. What is the difference between continuous and discontinuous traits?
2. Since the sickle-cell gene (Hb^s) usually leads to early death in persons homozygous for the trait, why is the gene so common in populations of African people?
3. A woman with blood type A (genotype AO) marries a man with blood type AB (genotype AB). Determine the possible blood types of their offspring.
4. Explain the nature of Klinefelter's syndrome and Turner's syndrome. How do these chromosomal aberrations occur?
5. Use the library to find information on sex-linked traits other than hemophilia and color-blindness. Why are these recessive genes normally expressed only in males?
6. Artificial selection has resulted in the development of many different breeds of dogs, cats, milk cows, and other animals. Select one type of animal and prepare a report on the various breeds, their particular qualities, and approximately when they were developed.
7. Natural selection is frequently important in the development of strains of bacteria resistant to antibiotics. Explain how natural selection operates in this situation.
8. Investigate the theory of evolution proposed by Jean Baptiste Lamarck. Why is this theory generally not accepted by modern biologists?
9. Prepare a report on the contributions of Louis and Mary Leakey to our understanding of human ancestry.
10. List some features of the skeleton of *Australopithecus africanus* that indicate that this creature may be a human ancestor.
11. One of the most famous hoaxes in science was known as Piltdown man. Find out about the Piltdown hoax and how it was discovered.
12. Many members of the dog family, Canidae, are familiar to most people. Find the scientific names of the following members of the family Canidae: gray wolf; red wolf; coyote; red fox; gray fox; arctic fox.
13. What is a species? What is the difference between a species and a population?
14. The dog is a member of the order Carnivora. Name some other animals that are also in this order but not in the family Canidae.
15. What are some of the problems that occur when using a two-kingdom (plant or animal) approach to classification?

Unit 3

MICROBIOLOGY



The world around us is filled with countless numbers of microscopic creatures. The air, the water, and the soil abound with invisible life. These microbes, or microscopic living things, are the subject of microbiology.

Viruses, the smallest of microbes, occupy the border between life and nonlife. Bacteria and other microbes are true living organisms, but most exist in the form of single cells. Of all the many microbes on earth, only a few are causes of disease. Many others perform useful and necessary functions. People have even learned to put microbes to work in manufacturing processes.

Investigation 26 from *Laboratory Investigations in Biology* can be done with this chapter.

13 *Viruses*



OBJECTIVES

- To understand the position of viruses as being at the fringes of life
- To appreciate the smallness of viruses
- To understand the historical development of virology
- To learn that viruses are different from living cells
- To understand that viruses differ from one another in their structure
- To learn how viruses are classified
- To learn that viruses obtain all of the energy and materials for replication from the host cell
- To learn that viruses disrupt the normal activities of the host cell
- To understand that viruses undergo mutation
- To explain the activities of bacteriophages
- To understand that the activities of phages are representative of the actions of animal and plant viruses
- To describe the differences between phages and animal viruses
- To understand the association between animal viruses and cancer
- To understand the action of interferon

The Nature of Viruses

13-1 What is a virus? As with many of the microbes, **viruses** (vī'rəs ez) were first identified as agents of disease. Influenza, measles, smallpox, and poliomyelitis are diseases caused by viruses. But what is a virus? Is a virus a living organism? There is no answer for either of these questions that is acceptable to all biologists. Perhaps it is simplest to view viruses as occupying a border between the living and the nonliving.

Viruses possess one of the most important characteristics of life. They are able to reproduce themselves just as all living organisms do. However, viruses do not have a system for transforming energy. Therefore they cannot grow more or respond to information from their environment. Viruses also lack the cellular organization that is characteristic of living things. They have no nucleus or other organelles and no cytoplasm. A virus must enter into a living host cell before it can reproduce.

While viruses lack many of the characteristics of life, there is good reason to consider them along with living organisms. This is because their body is made up of nucleic acid (either DNA or RNA) and proteins. These substances are always associated with life and are unlike the nonliving materials of this world.

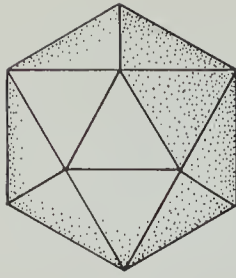
Viruses are extremely small particles. They are able to pass through the tiny pores of filters used to remove bacteria from liquids. It would take about 33 000 of the largest viruses, laid end to end, to cover 1 cm. Since viruses are so small, they cannot be seen with the ordinary light micro-

MAIN IDEA

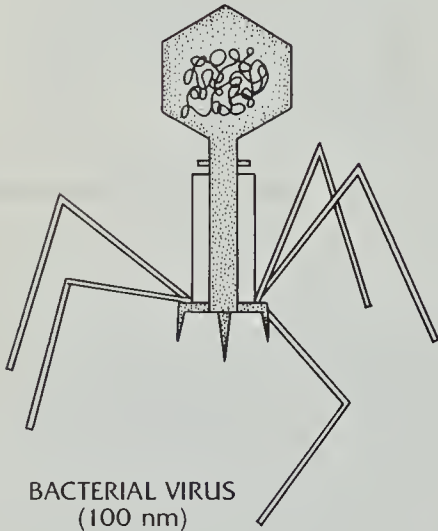
Viruses are extremely small particles composed of biological materials. Viruses can reproduce but they cannot be described as living because of their lack of enzymatic systems for energy metabolism.

SCIENCE BACKGROUND

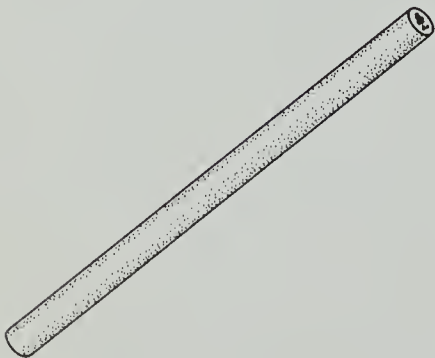
Living cells contain double-stranded DNA and single-stranded RNA. Viruses never contain both, but four configurations of a single nucleic acid exist in viruses: double-stranded DNA, single-stranded DNA, double-stranded RNA, and single-stranded RNA.



HUMAN RESPIRATORY VIRUS
(70 nm)



BACTERIAL VIRUS
(100 nm)



TOBACCO MOSAIC VIRUS
(15x300 nm)

FIGURE 13-1

The shapes of several different types of viruses are shown in the illustration above. The size of each type of virus is also indicated.

scope. Most of our knowledge about the structure of viruses had to await the development of the electron microscope. These modern instruments have shown viruses to exist in a variety of forms. Some have simple geometric shapes, such as spheres, cubes, and rods. Others take more complex forms with head and tail regions.

13-2 Viruses and history Virus diseases have been with us since the beginning of history. Examinations of the remains of ancient Egyptians have found skin markings closely resembling those left by smallpox. Other Egyptian remains show traces of poliomyelitis. Smallpox epidemics were recorded in China 3000 years ago. In fifteenth- and sixteenth-century Europe, smallpox was widespread and was considered to be an ordinary part of life. It was observed that a person who had contracted it and survived would almost certainly not get it again. This type of observation led to the first experiments with viruses.

In the 1790s Edward Jenner observed that dairy workers who had acquired cowpox from diseased animals were immune to smallpox. He reasoned that cowpox and smallpox must be similar and that exposure to one would cause immunity to the other. Jenner tested his idea by scratching some fluid from cowpox sores into the skin of a boy who had not had smallpox. The boy developed an immunity to smallpox. Jenner had invented vaccination and had succeeded in preventing a virus disease.

In 1884 Louis Pasteur had similar success in vaccinating people against rabies, another virus disease. There is no natural mild form of rabies with which to create immunity in humans. Pasteur had to create the mild form of the virus. He did this by obtaining material from the brain of a rabid dog and injecting it into a rabbit. When the rabbit died, Pasteur injected material from its brain into another rabbit. Each time this procedure was repeated, the virus caused a more severe disease in rabbits and a less severe disease in dogs. This weakened form, called an **attenuated** (ə ten'yū ā tid) **virus**, could then be used to vaccinate people. Pasteur's technique of producing attenuated viruses is still used today. The vaccines used against poliomyelitis and measles contain "live" attenuated viruses.

A few decades later, viruses that infect bacteria were discovered. Such viruses are called **bacteriophages** (bak tir'ē ə fāj es), or **phages** (fāj'es) for short. *Bacteriophage* means "bacteria eater." Bacteria and their viruses are easily grown in the laboratory. For this reason much of our information about viruses has come from the study of bac-

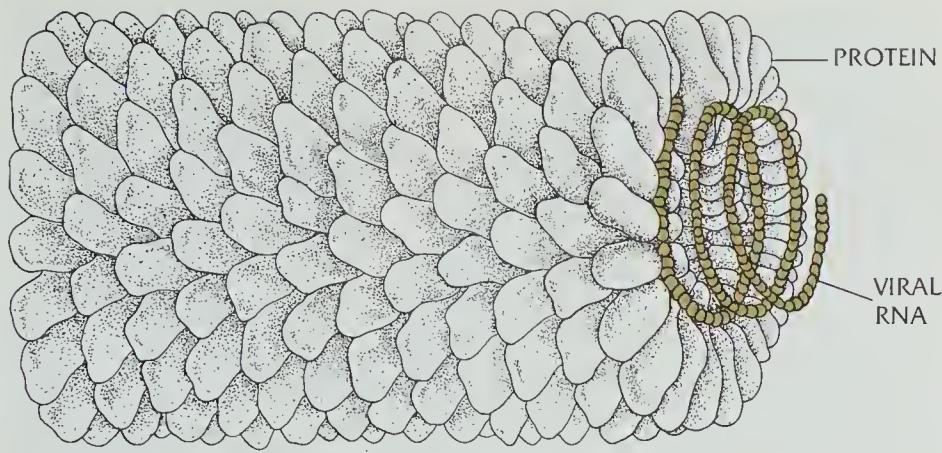


FIGURE 13-2 The tobacco mosaic virus consists of a coil of RNA surrounded by a protein coat that is in the form of a cylinder.

MAIN IDEA (13-2)

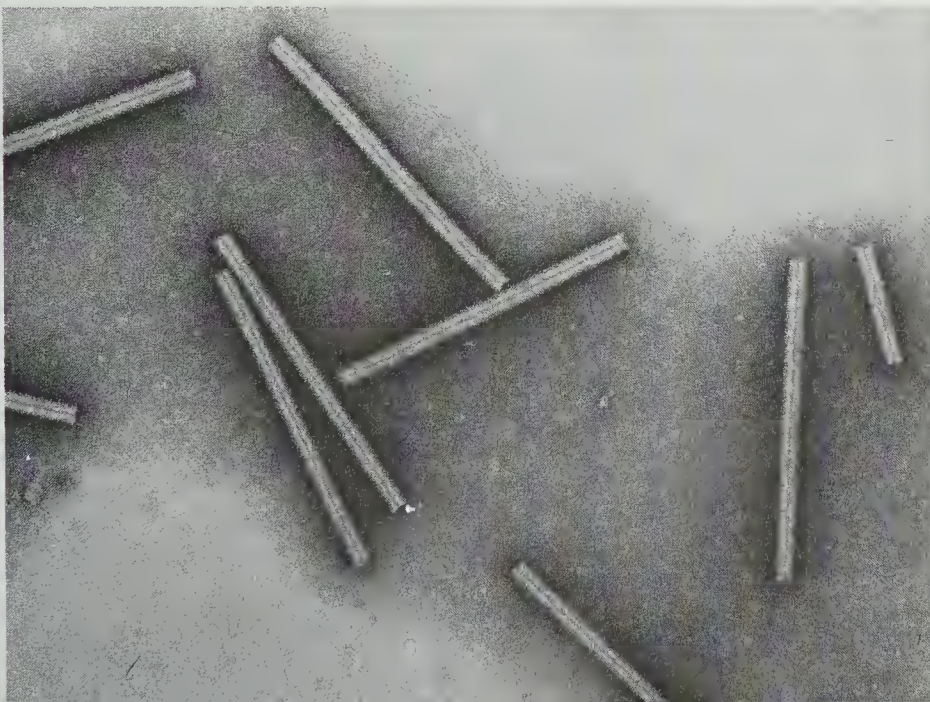
The distinction between viruses and other microbes was not recognized until the onset of the twentieth century. Most of our understanding of the viruses came after World War II with the advent of the electron microscope. Viruses now have an important role in genetic research.

SCIENCE BACKGROUND

Jenner's first vaccinations led to a milestone in human history. The World Health Organization (WHO) expects to declare the smallpox virus extinct in the early 1980s. A controversy has arisen about the maintenance of smallpox virus samples in laboratories. The WHO wants all samples destroyed except two, one in the United States and one in Moscow, for fear that escape of the virus from a lab would revive the disease.

terioophages. More will be said of phages later in this chapter.

An interesting development in virus research occurred in 1935 when Wendell Stanley was experimenting with the tobacco mosaic virus that infected tobacco leaves. He obtained a spoonful of fine needlelike crystals. These crystals could be treated like any other lifeless chemical. They could be dissolved and recrystallized, put on a shelf in a bottle, and then redissolved. Yet after all this, they could still produce the mosaic disease if rubbed onto a healthy tobacco plant. In the years before Stanley's work, others had shown that viruses could reproduce. It was assumed that anything that could reproduce must be living. So Stanley's discovery came as a shock. He found that viruses can withstand treatment that no living organism can. This raised many questions about the nature of life.



Several tobacco mosaic viruses, magnified 140 000 times, can be clearly seen in the photograph at left.



The spots on these tobacco leaves indicate that the plant is infected with tobacco mosaic virus.

After World War II, work centered on the viruses that are disease-causing, or **pathogenic** (path ə jen'ik). Originally it was thought that all viruses must be pathogenic. However, modern methods have allowed us to find that many viruses do no apparent harm. Some biologists now believe that all living cells—whether they are cells of animals, plants, or bacteria—are inhabited by viruses.

A recent development is the use of viruses in **genetic engineering**. Genetic engineering is the attempt to artificially change the genetic makeup of an organism. Viruses are being used to carry specific genes from one organism to another. One experiment involves the gene that specifies production of hemoglobin in the red blood cells of the mouse. A virus has been used to transfer this gene onto the chromosome of a bacterium. This technique holds promise of future application in curing inherited disorders in humans.

MAIN IDEA

Viruses are composed of nucleic acid and protein. The protein capsid surrounds the nucleic acid and takes a specific form in each type of virus.

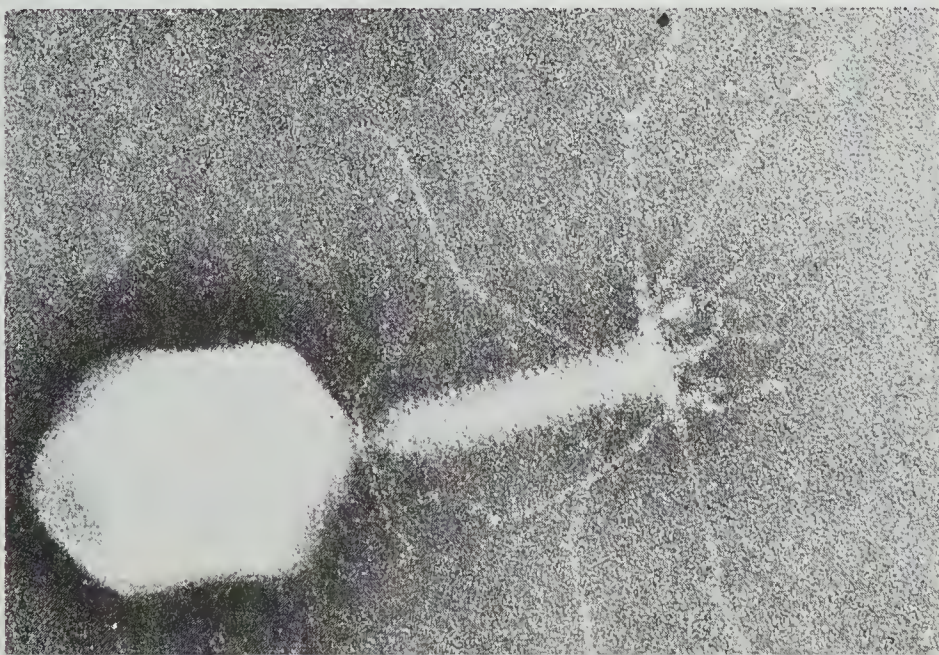
13-3 The structure of viruses Compared with living cells, viruses are rather simple. All viruses consist of at least two types of substances, protein and nucleic acid. Some of the more complex viruses may also contain lipids

or carbohydrates. The nucleic acid occupies the central, or core, region of a virus. Viruses contain only one type of nucleic acid. Some viruses contain DNA; others contain RNA; none contain both. In contrast, true cells always contain both DNA and RNA.

The nucleic acid of a virus is enclosed within a shell, or jacket, made of protein. This jacket is known as a **capsid** (kap'sid). The nucleic acid and the capsid together are called a **nucleocapsid** (nū klē ə kap'sid). Although all viruses have this core and capsid structure, each type of virus has its own specific features. The proteins of the capsid are of different composition in each virus. The proteins are arranged in units called **capsomers** (kap sə'mèrs). These capsomers are stacked, to form the capsid, as bricks are stacked to make a wall. The capsid of many viruses takes the form of an **icosahedron** (ī kō sə hě'drən). An icosahedron is a solid geometric figure having 20 faces. Other viruses, such as the tobacco mosaic virus, have their capsomers stacked in a **helical** (hel'ə kəl) pattern to form a hollow cylinder. The number of protein capsomers in a virus capsid varies from as few as 12 up to several thousand.

Some animal viruses have a **complex** structure, with the nucleocapsid surrounded by a membranelike **envelope** (en'və lōp). The envelope is covered with many spikes, which project outward from its surface. The envelope is thought to be derived from the membranes of the host cell and then modified by the virus. The spikes are found only on virus envelopes and not on the membranes of the host cell.

Compare this photograph of a bacteriophage (magnified 400 000 times) with Figure 13–3. Can you identify the head and tail regions?



SCIENCE BACKGROUND

The first complete chemical description of a set of genes was recorded in 1977. The DNA molecule of a particular bacteriophage was fully sequenced. It contains 5 836 nucleotides, which are divided into 10 genes that code for the proteins of the phage's capsid and the enzymes the phage uses to control the host cell.

SCIENCE BACKGROUND

One of the most remarkable properties of viruses is their capacity for self-assembly. Once the nucleic acid and all the proteins of the capsid are available, they come together spontaneously to form a complete virus. A built-in affinity between the various molecules is responsible.

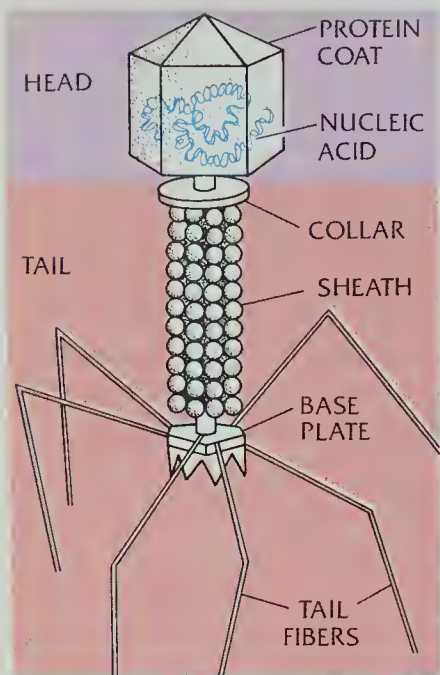


FIGURE 13-3
The detailed structure of a typical bacteriophage is shown above.

MAIN IDEA

Viruses are classified according to a combination of structural and chemical criteria.

SCIENCE TERMS

viruses
attenuated virus
bacteriophages
phages
pathogenic
genetic engineering
capsid
nucleocapsid
capsomers
icosahedron
helical
complex
envelope
virology

13-4 The classification of viruses Many hundreds of viruses are known and more are being identified each year. **Virology** (vī rol'ə jē), the study of viruses, is a young science, and its system of classification continues to change. The following is an explanation of the tests that are used in classifying viruses.

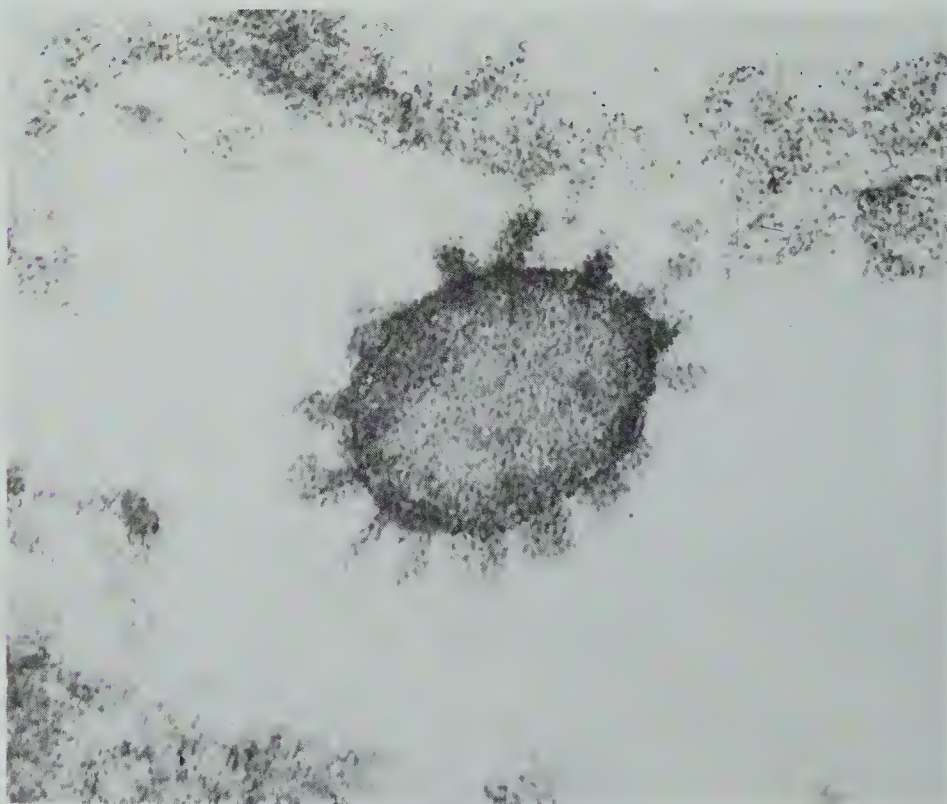
Nucleic acid—Viruses are divided into two broad groups, depending on whether they contain RNA or DNA.

Nucleocapsid structure—There are three categories of structure: icosahedral, helical, and complex.

Host-type—Viruses have a highly specific relationship with their host and are sometimes classified by their host-type. We speak of plant viruses, animal viruses, and bacterial viruses. The relationship between viruses and their host is even more specific than this indicates. Most viruses will infect only the cells of a single species or a group of closely related species. For example, tobacco mosaic virus will not infect corn or wheat. Many viruses even require cells of a specific kind of tissue as their host. Rabies virus infects only nervous tissue. Herpes viruses, which cause fever blisters and other diseases in humans, infect only skin and tissues that line body cavities.

Envelope: Animal viruses are divided by the presence or absence of an envelope.

The projections or spikes on the surface of this influenza virus aid the virus in attaching to the membrane of the host cell prior to penetration.



The four tests are used in combination to describe a virus. For example, herpes virus is an animal virus that contains DNA and has an icosahedral structure and an envelope. Tobacco mosaic virus is a plant virus that contains RNA and has a helical structure but no envelope. Bacteriophage T-2 is a bacterial virus that contains DNA and has a complex structure but no envelope.

CHECK YOUR FACTS

1. Who gave the first vaccination?
2. What sort of device is needed to see viruses?
3. Some people believe that virus diseases are of recent origin. Is this true?
4. Are viruses made up of cells or are they like cells?
5. Where in a virus is the nucleic acid found?

The Activities of Viruses

13-5 Viruses as parasites We have seen that viruses always contain nucleic acid and protein. Why do they always contain these two substances together? In living organisms, DNA is the genetic material. DNA stores information on how to make the proteins that living cells need. In viruses, the nucleic acid in the core stores the information needed to make the proteins of the capsid.

A virus can be compared to a fancy wooden case with a blueprint locked inside. The capsid is the case. The nucleic acid is the blueprint, with all the instructions needed to make more wooden cases and more blueprints. But the blueprint cannot do this alone. Raw materials, tools, and energy are needed to make the copies. Where can all these things be found? They can be found inside a living cell. Amino acids and nucleotides are the raw materials. Ribosomes and transfer RNA are the tools. Energy is there to do the work.

Viruses cannot multiply on their own. They can multiply *only* when they are within living cells. The multiplication of viruses is called **replication** to distinguish it from the reproduction of cells. When a virus replicates, it uses the substances and the chemical machinery of the host cell. This may interfere with the normal activities of the host. The proteins needed by the host cell cannot be synthesized if ribosomes are busy assembling capsid proteins. The host is deprived of the energy and the chemicals that are consumed during virus replication. The new copies of the virus may take up needed space in the nucleus or cyto-

ANSWERS TO CHECK YOUR FACTS

1. Edward Jenner.
2. An electron microscope.
3. No. Virus diseases have been known since ancient times but were only recently diagnosed.
4. No. Viruses lack most of the structural and functional features of cells.
5. In the center, or core.

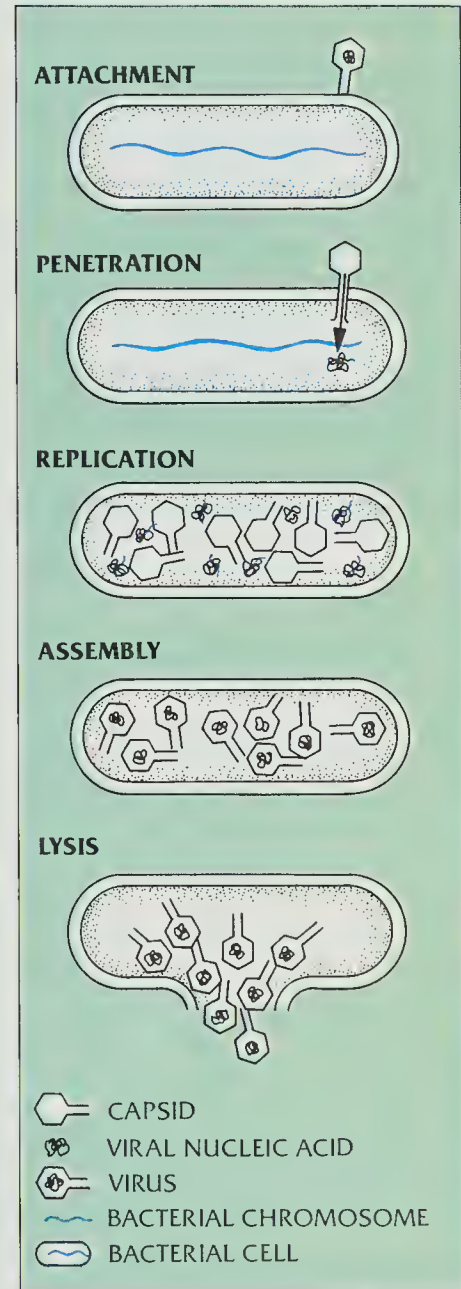


FIGURE 13-4

The destruction of a bacterial cell by a bacteriophage infection is illustrated in this figure.

SCIENCE BACKGROUND

How can an RNA virus attach its nucleic acid to the host chromosome, which contains DNA? Some RNA viruses have been found to produce an enzyme called reverse transcriptase. This enzyme reverses the usual order of events and synthesizes DNA from an RNA template. Thus an RNA virus can leave behind its genes as DNA integrated with the host's DNA.

MAIN IDEA

Bacteriophages act in one of two ways: Virulent phages replicate actively and cause lysis of their hosts. Temperate phages may be carried through many generations of bacteria as prophages attached to the bacterial chromosome.

plasm of the host. The new viruses may then burst out of the host cell, causing its death.

A virus can also be changed by its host cell. This is what Pasteur discovered when he produced the attenuated rabies virus. The **virulence** (vir'yə ləns), or potency, of a virus is influenced by the cells in which it replicates. When rabies virus is grown in brain cells of dogs, its virulence for humans increases. When this virus is grown in rabbit cells, its virulence for rabbits increases and its virulence for humans decreases. These changes in virulence may be caused by mutations in the virus nucleic acid. Such mutations may cause a change in the virus structure or a change in host preference.

13–6 Bacteriophages Bacteriophages are the source of much of our knowledge about the activities of viruses. Animal and plant viruses act in much the same way as phages, but they are more difficult to experiment with. Bacteriophage T-2 is often used in research. Bacteriophages are grown on cultures of bacteria. Bacteria are allowed to form a uniform film on the surface of agar in a petri dish. Sometimes, clear glassy areas develop within the layer of bacterial growth. These clear areas are called



Several bacteriophages can be seen attached to the surface of the much larger bacterial cell. The viral nucleic acid will enter the bacterial cell through the tail of the virus.

plaques (plaks). A plaque is an area in which a phage has destroyed all the bacteria. The bacteria burst open after replication of the virus. This bursting is known as **lysis** (lī'sis). A bacteriophage that causes lysis is a **virulent** (vir'yə lent) **phage**.

When a virulent phage replicates, it attaches its tail end to the bacterium. Molecules on the virus's tail form a close fit with substances on the bacterial surface. This matching fit is one of the reasons why each virus infects a specific host. After attachment, an enzyme in the tail of the virus makes a hole in the cell wall of the bacterium. Then the hollow tail of the virus shortens. The nucleic acid is pushed into the bacterium. The empty capsid remains outside. It is almost as if the nucleic acid were injected into the host with a syringe.

Once the viral nucleic acid is inside the bacterium, it takes control. The chromosome of the host cell is either destroyed or inactivated. The normal metabolism of the bacterium stops. Its biochemical machinery is used to synthesize copies of the viral nucleic acid and new viral protein. As these substances become available, new virus particles are assembled. The bacterium undergoes lysis after a large number of viruses have been formed. The entire process, from penetration to lysis, is called a **lytic** (lit'ik) **cycle**. Phages take from 25 to 45 min to complete a lytic cycle. About 200 to 300 new viruses are produced. Each of these new viruses is free to infect another bacterium and start another lytic cycle. In just a few hours, the offspring of a single phage can destroy a billion bacteria! This happens in concentrated laboratory cultures of bacteria. In nature, however, bacteria are spread out in the soil or water. The phages escaping after the lysis of one bacterium may not find another bacterium of the same type nearby. Phage infections spread much more slowly in nature than in the laboratory.

Some bacteriophages do not cause lysis of their host. They are called **temperate** (tem'per it) **phages**. A temperate phage injects its nucleic acid into a bacterium just as a virulent phage does. But the temperate phage does not take control of the cell. Instead, the nucleic acid of the phage is attached to the chromosome of the bacterium. The viral nucleic acid acts as an extra set of genes on the bacterial chromosome. The viral nucleic acid is called a **prophage** (prō'faj) while it is in this condition. The bacterium continues its normal activities, including metabolism and cell division. Each time the bacterium divides, the viral genes are also duplicated. All the daughter cells carry a prophage on their chromosomes.

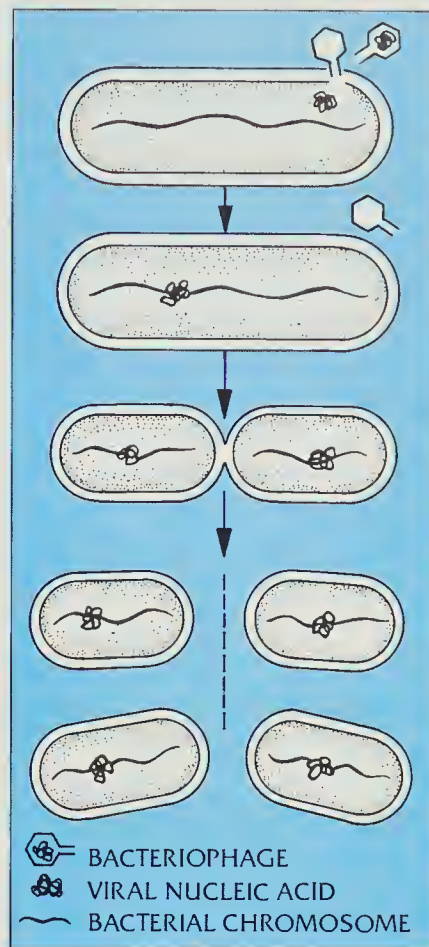


FIGURE 13-5

The nucleic acid of a temperate phage becomes attached to the bacterial chromosome and is replicated along with the bacterial genes during cell division. A prophage can become virulent again at a later time.

SCIENCE BACKGROUND

Animal cells often give visual manifestation of virus infection before their death. Inclusion bodies are found in either the nucleus or the cytoplasm, depending on which site a particular virus replicates in. Some viruses induce formation of giant multinucleate cells, probably by causing cells to fuse.

MAIN IDEA

Animal viruses differ from phages in only a few details of their activities. Viruses acting similarly to temperate phages are the apparent cause of many cancers in animals.

A prophage can be carried through many generations without apparent harm to the bacteria. However, sometimes the prophage becomes separated from the host chromosome. When this happens, the phage enters a lytic cycle. It replicates and its offspring infect other bacteria. The cause of the differences between virulent and temperate phages is not known. Also not known is the reason why a prophage is sometimes activated to become virulent again. A possible explanation is that some bacteria might contain chemicals that prevent a phage from replicating. This might cause the phage to act in a temperate manner. At some later time, the bacteria might lose the ability to make the inhibiting chemicals. If this happens, the phage would become virulent again.

Animal and plant viruses replicate just as phages do. They also rob their host cell of their resources. Animal and plant viruses sometimes attach their nucleic acid to a host cell chromosome, just as temperate phages do.

13-7 *Animal viruses and cancer* There are differences between the action of phages and the action of animal viruses. Animal viruses cannot inject their nucleic acid into cells. After attaching to a cell membrane, an animal virus is taken into the cell by phagocytosis. The animal virus is uncoated inside the host cell. Enzymes of the host dissolve the virus's capsid. Once uncoated, animal viruses behave almost exactly like phages except that they are slower. Phages complete their replication in less than an hour. Animal viruses require six or more hours to replicate. Animal viruses are also released more slowly from their host cell than phages are, causing a more gradual disintegration and death of the cell. Some animal viruses differ from phages in that they have envelopes. It is believed that these envelopes are taken from the membranes of the host. Animal viruses enter and leave their host cell differently than phages do. However, they are very similar in their activities while inside the host cell.

The common cold is the result of viruses replicating in the cells that line the respiratory tract. The activities of the virus kill some of these cells, but this does no real harm. Cells that line the respiratory tract are always dying and being replaced anyway. It is the attempt to get rid of the virus that makes us uncomfortable. The respiratory tract produces excess mucus to flush the virus particles out. The mucus accumulates, causing congestion, sneezing, and coughing. Meanwhile, the virus infection stops.

More and more animal cancers have been shown to be caused by viruses. Viruses that cause cancer are called **on-**



Some viruses have been shown to cause cancer in animals. Research concerning a link between viruses and cancer in humans is continuing.

cogenic (ong kə jen'ik) **viruses**. Three microbiologists, Howard Temin, David Baltimore, and Renato Dulbecco, received the Nobel Prize in 1975 for their work with oncogenic viruses. They explained how these viruses attach their nucleic acid to a host cell chromosome. Oncogenic viruses behave like temperate phages. After penetrating a cell, they cause their nucleic acid to be included into one of the chromosomes of the host. The viral nucleic acid acts like an extra set of genes in the animal cell. These viral genes cause many changes in the host cell. New kinds of materials may be synthesized. The cell may begin to divide more rapidly or more frequently than it did before infection. Daughter cells result in huge numbers. A cancerous growth is formed!

SCIENCE BACKGROUND

The Epstein-Barr (EB) virus has been strongly associated with two types of human cancer: Burkitt's lymphoma and nasopharyngeal carcinoma. Samples of these two neoplasms obtained from all over the world have almost invariably contained the EB virus. Injection of this virus into monkeys produces a cancer that mimics Burkitt's lymphoma. EB virus is also known to be the cause of infectious mononucleosis.

SCIENCE BACKGROUND

Oncogenic viruses exist in two classes. Those containing DNA are the oncoviruses. Those containing RNA are the oncornaviruses. Oncornaviruses depend on the action of reverse transcriptase.

SCIENCE TERMS

replication
virulence
plaques
lysis
virulent phage
lytic cycle
temperate phages
prophage
oncogenic viruses
interferon

MAIN IDEA

Interferon is a protein produced by virus-infected animal cells to protect neighboring cells against infection.

SCIENCE BACKGROUND

Interferon may act on ribosomes. It may cause subtle changes in the structure of ribosomes so that they will continue to translate host RNA into protein but will not translate viral RNA.

ANSWERS TO CHECK YOUR FACTS

1. Instructions to make the proteins of the capsid.
2. They lack the energy, the metabolism, and the organelles needed to make their proteins.
3. Energy and raw materials.
4. The ribosomes are occupied in making capsid proteins.
5. The bursting of a cell.
6. No. It remains outside.

Do viruses cause cancer in humans? The likely answer is yes, but it is difficult to prove. Viruses have been found repeatedly in some types of human cancer cells. Finding a virus inside a cancer cell does not prove that the virus caused the cancer. Viruses exist in many cells without producing any visible harm. Getting evidence that a virus causes cancer in a laboratory animal is not difficult. The surest way is to inject the virus into an animal and see if a cancer develops. If it does, then the virus should be isolated from the cancer and injected into a second animal. If the second animal develops the same type of cancer, the virus must be the cause. Proof that viruses cause cancer in humans must await the development of new research methods. It must also be understood that viruses probably do not cause any type of cancer on their own. Other factors are generally involved. For example, certain irritating chemicals may act together with viruses to produce the disease.

13-8 Defense against viruses Viruses are all around us. Their ability to multiply is great. Why do we not suffer constantly from virus diseases? There are two reasons. The first is our system of immunity, which defends us against all types of microbes. The second is a substance called **interferon** (in tər fir'on). Interferon is a protein that protects animal cells against infection by viruses. When an animal cell is invaded by a virus, the cell produces interferon. The interferon diffuses to neighboring cells and makes them resistant to the virus. It is thought that interferon does this by preventing the synthesis of viral proteins. Interferon does not affect the synthesis of normal cell proteins. Interferon is effective in very small amounts. A single molecule can protect a cell against infection. Unfortunately this protection is temporary, and it is not equally effective against all viruses.

Perhaps the natural defense by interferon can be improved. Much research has been directed toward this goal, but several problems have turned up. Each species of animal produces a different form of interferon. Interferon only protects cells of the species in which it is produced. Also, interferon is only produced in small amounts. There is no ready source of enough interferon to use it as an antiviral drug in humans.

Recently attempts have been made to stimulate the body to increase its own production of interferon. The search is on for a drug that can do this without side effects. Such a drug would hold promise of a new era in the treatment of virus diseases.

CHECK YOUR FACTS

1. What information is in the nucleic acid of a virus?
2. Why can't viruses multiply on their own?
3. What does a virus take from its host when it replicates?
4. Why can't the host cell make its own proteins while the virus replicates?
5. What is lysis?
6. Does the capsid of a phage penetrate the host?

SUMMARY

Viruses are very small particles of nucleic acid and protein. They can reproduce and pass on their characteristics to their offspring. Viruses are not cellular. They lack most of the properties of life.

A virus must enter a living cell in order to replicate. Each virus requires a specific type of host cell. Much information about the activities of viruses has come from studying bacteriophages. The viral nucleic acid takes control of the host cell's metabolism. The energy and the chemicals of the host are used in building new viruses.

REVIEW QUESTIONS

1. Give two reasons for considering viruses with living organisms.
2. What are some differences between phages and animal viruses?
3. What happens to the host cell during virus replication?
4. What difficulties have prevented the use of interferon as a drug?
5. Why is it difficult to prove that viruses are associated with cancer in humans?
6. How do viruses change?
7. What are the differences between virulent phages and temperate phages?
8. Oncogenic viruses act similarly to temperate phages. Explain.
9. Are all viruses pathogenic?

ANALYSIS AND APPLICATION

1. Present arguments for and against the proposition that viruses are living.
2. Viruses lack many of the properties of life. Which of these deficiencies seems most important?

ANSWERS TO REVIEW QUESTIONS

1. Their ability to reproduce and their composition of materials associated with life.
2. Animal viruses act more slowly, they do not inject their nucleic acid into the host cell, and some animal viruses have envelopes.
3. It is deprived of energy and nutrients; its metabolism is interrupted. These changes lead to injury or death.
4. Only human interferon is effective, and it cannot be obtained in large enough quantities.
5. Because it would be unethical to do the necessary experiments in humans.
6. By mutation and through the influence of the host cell.
7. Virulent phages replicate actively and kill their host. Temperate phages attach their nucleic acid to the host chromosome and may exist as prophages for a long time.
8. Both types of viruses integrate their genetic material with that of the host.
9. No.

ANSWERS TO ANALYSIS AND APPLICATION

1. *The arguments for:* Viruses exhibit reproduction, heritability, and mutability. Viruses are composed of life-associated materials.
The arguments against: Viruses do not exhibit metabolism, motility, or responsiveness. They lack cellular organization.
2. Their lack of energy-processing systems may be viewed as the basis of their inability to grow, to be motile, and to be responsive. This lack may also be viewed as the basis of the obligatory intracellular parasitism of viruses.

Investigations 27–29 from *Laboratory Investigations in Biology* can be done with this chapter.

OBJECTIVES

- To explain the distinction between procaryotes and eucaryotes

14 *Monera*



- To explain the distinction between colonial forms and multicellular life
- To describe fermentation
- To understand that each type of bacteria has unique activities
- To define pasteurization
- To learn that the Gram stain is a fundamental procedure in bacteriology
- To describe the shapes of bacteria and how they are named
- To understand the structural features of bacterial cells
- To discuss motile and non-motile bacteria
- To understand that bacteria become dormant during adverse conditions
- To state the modes of nutrition in bacteria
- To understand that fermentation replaces respiration as a means of energy production in anaerobic conditions
- To explain nitrogen fixation
- To explain binary fission
- To understand the formation and the function of spores
- To reinforce the idea that sexual reproduction promotes genetic variation and adaptability
- To describe the growth pattern of bacteria
- To understand that mycoplasmas and rickettsias are classified with the bacteria
- To describe the distinguishing features of blue-green algal cells
- To understand that most blue-green algae occur as filamentous colonies covered by a mucoid sheath
- To explain the distribution and growth habits of blue-green algae

The Monerans

14-1 The simplest cells From viruses, at the fringes of life, we move on to the simplest cells. These are the bacteria and blue-green algae, which are the only organisms with procaryotic cells. Because their cells are so different, bacteria and blue-green algae are classified in a kingdom by themselves. This is the **kingdom Monera**, and these organisms are called **monerans**. The monerans of today's world are probably like the first cells that lived more than 3 billion years ago.

Procaryotic cells are more simply organized than eucaryotic cells. The enzymes that do the work of a procaryotic cell are on the plasma membrane or scattered in the cytoplasm. They are not enclosed in complex organelles. The chromosomes of procaryotic cells are also in the cytoplasm, instead of in the nucleus as they are in eucaryotic cells. In procaryotic cells the chromosomes exist as simple DNA molecules. The DNA does not have a jacket of protein as it does in eucaryotic chromosomes.

There are two types of organelles found in procaryotic cells. These are the ribosomes and the **flagella**. Flagella are threadlike structures that propel cells through liquids. The ribosomes of procaryotic cells are smaller than those of eucaryotic cells, and the flagella have a simpler structure.

Monerans exist as single cells (**unicellular organisms**) or as colonies. A **colony** (kol'ə nē) is a group of similar cells that are attached to each other. The colonies of moneran cells are not to be thought of as **multicellular**

MAIN IDEA

The kingdom Monera comprises the bacteria and blue-green algae, which are procaryotic organisms.

SCIENCE TERMS

kingdom Monera

monerans

flagella

unicellular organisms

colony

multicellular organisms

phylum Schizomycetes

phylum Cyanophyta



Blue-green algae, such as *Nostoc* shown above, and bacteria are classified in kingdom Monera because of the procaryotic organization of their cells.

(mul ti sel'yə lər) **organisms**. The cells in these colonies are each capable of independent life. They do not depend on or cooperate with each other. A human is a true multicellular organism. A single human cell cannot survive on its own. It depends on the cooperation of other cells to supply its needs. Organisms can be found in three levels of complexity: unicellular, colonial, and multicellular. Monerans exist only at the first two levels.

The kingdom Monera has two subdivisions. The **phylum Schizomycetes** (skiz'ō mī sēts), meaning "splitting fungus," contains the bacteria and their relatives. This refers to the simple form of division that occurs in bacteria. The **phylum Cyanophyta** (sī'ə no fī tə), meaning "blue-plants," includes the blue-green algae.

The monerans are simple organisms. But that does not mean that they are unsuccessful or unimportant. There are about 1 500 species of blue-green algae and more than 15 000 species of bacteria known to biologists today.

ANSWERS TO CHECK YOUR FACTS

1. Bacteria and blue-green algae, or all procaryotes.
2. Ribosomes and flagella.
3. A group of similar cells attached to each other.
4. Procaryotic chromosomes do not have a jacket of protein.

CHECK YOUR FACTS

1. What kinds of organisms are found in the kingdom Monera?
2. What organelles are found in procaryotic cells?
3. What is a colony?
4. How do procaryotic chromosomes differ from eucaryotic chromosomes?

Bacteria

14–2 The study of bacteria The first scientific description of bacteria was made about 1675 by Anton van Leeuwenhoek. Leeuwenhoek built his own microscopes to look at many strange things, such as saliva and polluted water. In all these things he found tiny creatures swimming about. He did not know what they were, so he called them little animals because they could move. Leeuwenhoek made drawings of what he saw, and wrote descriptions of their movements. He sent his descriptions to a scientific club in England where they were read in public. This was how **bacteriology** (bak tir ē ol'ə jē), the study of bacteria, got its start.

Louis Pasteur experimented with bacteria from the 1850s until his death in 1895. Pasteur started out as a chemist and was made a professor at the University of Lille in France. Lille was an agricultural center, producing wine and alcohol by fermenting the juice of sugar beets. **Fermentation** (fēr men tā'shən) is the conversion of sugar into alcohol or other substances. It is done by microbes working without oxygen. People at that time thought that fermentation was a natural chemical process. If they left grape juice or beet juice in a warm place, it fermented into alcohol by itself. People did not know that microbes actually do the work.

One day there was a problem at one of the sugar beet fermentation plants. Some of the vats of beet juice were turning sour instead of making alcohol. Professor Pasteur was called from the university to help. He took samples from the vats that were making alcohol and from those that were turning sour back to his laboratory. He looked at both juices with his microscope. In the juice that was fermenting properly, he found many yeast cells. These yeast cells were dividing. As their number increased, so did the amount of alcohol in the juice.

Pasteur found no yeast in the sour juice. Instead, he found some rod-shaped bacteria. These were multiplying too. And as they did, the sourness of the juice increased. Pasteur found that the bacteria were making lactic acid. Lactic acid is the substance that makes old milk taste sour.

Pasteur went on to study other kinds of fermentations. He studied the fermentation of grapes and other fruits into wine and the souring of milk and butter. In each type of fermentation he found a different microbe. Each microbe makes a different product. Some convert fruit sugars into alcohol, and others convert milk sugar to lactic acid.

Pasteur had found out what was wrong at the alcohol factory. The wrong microbes had gotten into some of the

MAIN IDEA

Bacteria were first described three centuries ago. By the 1880s the varieties and the activities of bacteria began to be categorized. Louis Pasteur played a central role in the rise of bacteriology.

SCIENCE BACKGROUND

The Gram-stain reaction predicts the susceptibility of bacteria to antibiotics. Only gram-positive bacteria are susceptible to penicillin. Only gram-negative bacteria are sensitive to polymyxin B. Both groups are sensitive to tetracycline.

SCIENCE BACKGROUND

Bacterial cell walls contain complex polymers of amino sugars and amino acids in a latticelike network. These are called peptidoglycans.

SCIENCE BACKGROUND

Gram-positive bacteria have cell walls composed of peptidoglycans. Cell walls of gram-negative bacteria contain fatty substances along with the peptidoglycans.

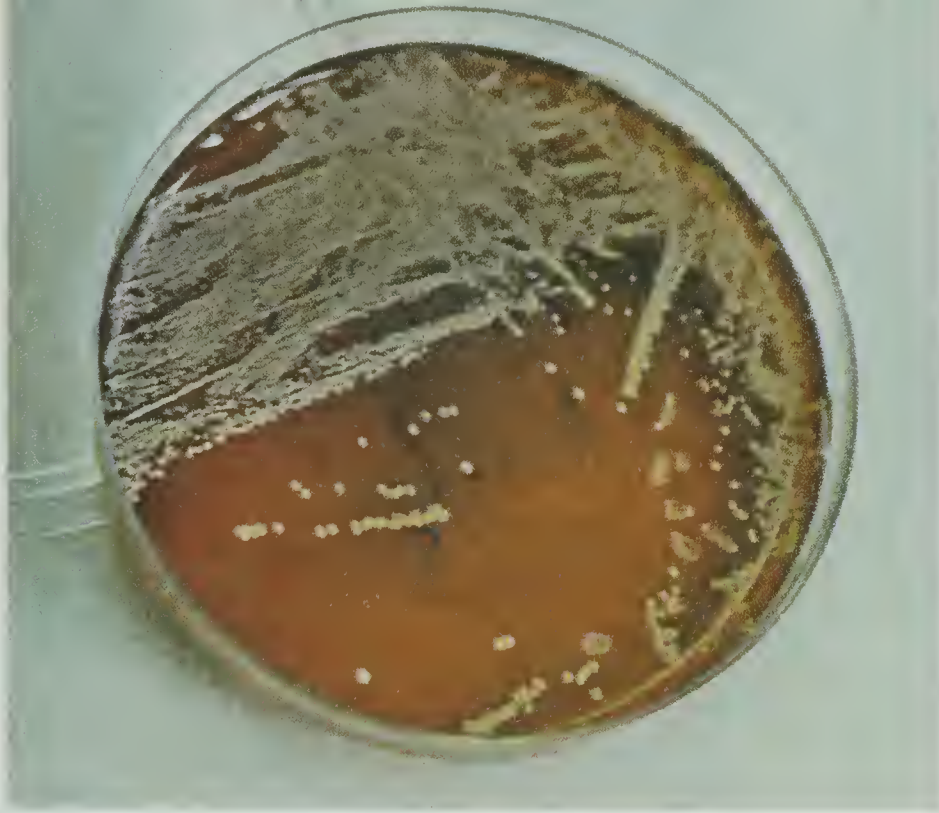
vats. What could be done about it? Pasteur discovered that heating the juices to 63°C for 30 min would kill most of the microbes. Then rapid cooling would slow the growth of any remaining bacteria. This is the process we know today as **pasteurization** (pas chər ə zā'shən). Pasteurization was used to stop the growth of lactic acid bacteria in the beet juice. Then the proper yeast was added to ferment the juice to alcohol. Today pasteurization is used in preparing milk, wine, beer, and other products.

Pasteurization cured the problems of the alcohol makers in Lille. Later it stopped the spread of disease through infected milk. But Pasteur's work with fermentation had other important results too. This was the beginning of real knowledge about bacteria and other microbes. Different bacteria grow on different foods. They each make different products. Bacteria float on dust particles in the air. Whenever they settle in a moist place, they start to grow. From these observations Pasteur got the idea that bacteria might be the cause of human disease.

Pasteur was an excellent scientist, but he was also a good talker. He loved to tell people about his experiments and his ideas. His ideas about microbes and disease soon spread all over Europe. Other scientists began to look for proof that bacteria could cause disease. By the 1880s, many kinds of bacteria were identified. Some were found to cause disease, but others turned out to be harmless.

In 1884 a Danish biologist named Hans Gram developed a staining method for identifying bacteria under the microscope. The **Gram stain** divides bacteria into two groups. Some bacteria accept the dye and are called **gram-positive**. Other bacteria are not colored by the stain. These are called **gram-negative**. The stain works because the two kinds of bacteria have different chemicals in their cell walls. A century later the Gram stain is still the most widely used stain for bacteria. It is usually used as the first step in identifying unknown bacteria.

Many methods have been developed for growing bacteria and studying them in the laboratory. A group of microbes grown artificially in the laboratory is called a **culture** (kul'chər). Growing cultures of bacteria requires a **culture medium** (pl. *media*). This can be either a liquid or a moist solid that provides the bacteria with food. Beef broth is a good liquid culture medium. Most solid culture media are made with agar. **Agar** (ä'gər) is a gelatin-like substance obtained from seaweed. Agar provides a firm surface for bacteria to grow on, but it is not a good food for them. Foods must be added to the agar. One of the best culture media is made by mixing agar with sheep's



Bacterial colonies can be seen growing on the surface of the agar in the photograph above. A nutrient substance is added to agar to support growth.

blood. Blood agar will support the growth of almost any type of bacteria.

Liquid culture media are kept in test tubes, but agar media are often put in **petri** (pā'trē) **dishes**. A petri dish is a flat glass dish with a matching glass cover. Bacteria growing on the agar can be seen without opening the dish.

14-3 The shapes of bacteria Bacteria are much larger than viruses. Many can be seen with the high-power lens of a light microscope. It is because of this that bacteria were being identified over a century ago. The shape of bacteria can be seen with a light microscope. However, an electron microscope is needed to see details of their internal structure. Although bacteria are larger than viruses, they are much smaller than plant or animal cells.

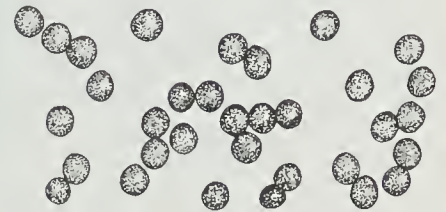
Bacteria are found in a variety of forms. Some grow as single cells. Others remain attached after dividing and form chains or clusters. Bacteria can be placed in three groups based on their shape.

1. **Cocci** (kok'sī) (sing. *coccus*): These are sphere-shaped cells. Some cocci are found in pairs, or *diplococci*. An example is *Diplococcus pneumoniae*, the bacterium that causes bacterial pneumonia. Other cocci form chains or threads. These are the *streptococci*. One type of *streptococcus* is the cause of strep throat. *Staphylococci* are cocci that form grape-like clusters (*staphylo* is the Greek word

BACILLI



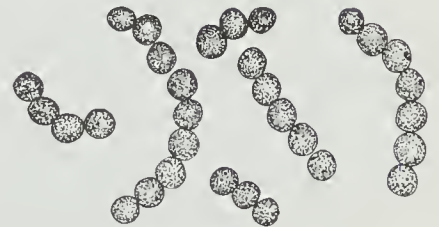
COCCI



SPIRILLA



STREPTOCOCCI



STAPHYLOCOCCI

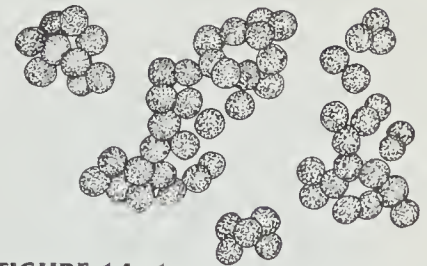


FIGURE 14-1

There are three basic groupings of bacteria based on shape. However, subgroups based on chain and cluster formation are also recognized.

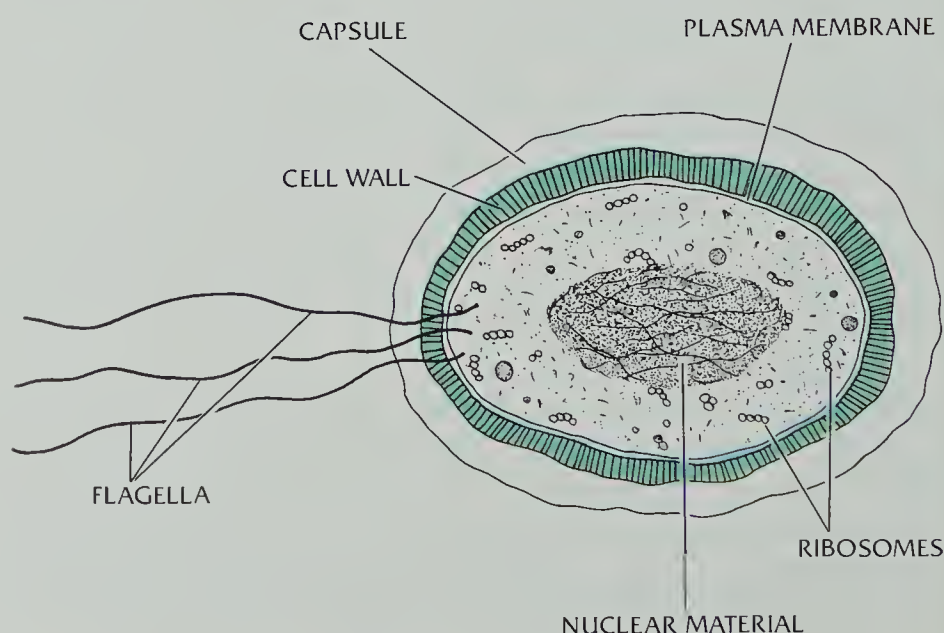
for “grape”). *Staphylococcus aureus* normally lives on human skin. Sometimes it gets into the skin and causes abscesses, or boils.

2. **Bacilli** (bə sil’ī) (sing. *bacillus*): These are bacteria shaped like rods, or cylinders. *Escherichia coli* is a gram-negative bacillus that lives in the human intestine. Its name is often shortened and written *E. coli*. *E. coli* has been used in a great many experiments in genetics and biochemistry. We probably know more about *E. coli* than any other organism on earth. *Streptobacilli* are bacilli that grow in chains. They look something like strings of sausages. Some of the lactic acid bacteria first discovered by Pasteur are gram-positive streptobacilli.

3. **Spirilla** (spī ril’ə) (sing. *spirillum*): These are cells that take the shape of twisted rods, or corkscrews. Spirilla grow as single cells, not as chains or clusters. Bacteria of the genus *Spirillum* are soil microbes. Their activities improve the fertility of the soil.

While bacteria come in many shapes and sizes, they all have cellular structures in common. The DNA of bacteria is not separated from the cytoplasm by a nuclear membrane. The DNA is usually found in the central area of the cell and is called the nuclear material or nuclear area. The cytoplasm of bacteria contains ribosomes and granules of stored food materials. The cytoplasm is enclosed in a plasma membrane. The inside of the membrane carries the enzymes of respiration. These are like the enzyme in the mitochondria of eucaryotic cells.

FIGURE 14-2 The structure of a typical bacterium is shown in the illustration below. Not all bacteria have flagella or a capsule.





The flagella of the bacterium Proteus vulgaris are clearly visible in the electron micrograph above.

Outside the plasma membrane is the cell wall. The cell wall is not living. It is a cell product that gives the bacterium its shape. Bacteria used to be classified as plants because plants and bacteria both have cell walls. We know today that bacteria cell walls and plant cell walls are made of different chemicals. Some bacteria have a second nonliving layer outside the cell wall. This is the jellylike **capsule** (kap'sol). Although the capsule is nonliving, it affects the properties of bacteria. *Diplococcus pneumoniae* is highly virulent when it has a capsule. If it is made to grow without a capsule, it loses its virulence.

Flagella are found on many types of bacilli and spirilla. Only a few species of cocci have flagella. Bacteria use flagella to propel themselves through water or other liquids. The flagella start in the cytoplasm and pass out through the plasma membrane, cell wall, and capsule. Flagella beat with a very rapid, whiplike motion. Some flagella move at a rate of over 2 000 beats per minute. Bacteria may have one flagellum or many. The flagella may be in groups at the ends of the cell, or they may be spread all around the cell. Bacteria that have flagella and can move are **motile** (mō'tal). Bacteria that lack flagella are usually nonmotile. A few bacteria without flagella can move with a side-to-side motion like that of a snake.

SCIENCE BACKGROUND

The chemicals of the cell wall are unique to bacteria. The human immune system recognizes these as foreign and attacks the bacteria. Bacterial capsules are composed mostly of polysaccharides and may mask the foreign cell wall. This may be the reason for the virulence of capsulated forms.

SCIENCE BACKGROUND

In addition to ribosomes and flagella, bacteria have one other organelle. This is the *mesosome*, a structure composed of folded membranes. Its function is uncertain, but it may be concerned with energy production.

MAIN IDEA

Bacteria have specific requirements of moisture, darkness, temperature, and nutrient source for active growth. Most bacteria are either parasitic or saprophytic heterotrophs; a few are autotrophic. Bacteria vary in their metabolism from strictly aerobic to strictly anaerobic.

14-4 Growth and nutrition The activities of bacteria are not constant. Bacteria are a little like bears that hibernate, or go to sleep, to escape the winter. When conditions are right, bacteria grow and reproduce very actively. If conditions become unfavorable, bacteria stop their activities and become almost lifeless. Bears sleep during one season of the year. Bacteria can switch back and forth, from active to inactive, as often as is needed. But what are the “right conditions” for bacteria?

First, bacteria require moisture. Like all living cells, bacteria contain much water. Dry surroundings cause bacteria to lose water and become inactive.

Second, bacteria are sensitive to temperature changes. Each species has a temperature at which it grows best. A few bacteria can grow at temperatures near 0°C. A few have even been found in Antarctica where they grow at -7°C. The majority of bacteria prefer temperatures of 25°C to 40°C. A few species can grow at temperatures as high as 75°C. Bacteria that cause disease in humans grow best at body temperature (37°C).

Third, most bacteria grow best in darkness. The ultraviolet rays in sunlight can cause mutations or even kill bacteria. One family of bacteria is not harmed by light. These are the **phototrophic** (fō tō trāf'ik) bacteria, which use light energy to carry on photosynthesis, just as most green plants do.

Fourth, a suitable food source is necessary for the growth of bacteria. As Pasteur discovered, each kind of bacteria uses different foods.

Most bacteria cannot carry on photosynthesis. Instead they use organic materials that have been made by other organisms. Bacteria that take food from living organisms are parasites. Bacteria that use dead organic matter as their food are **saprophytes** (sap'rə fīts).

Bacteria and animals nourish themselves differently. Animals digest their food *after* they take it in. Bacteria digest their food *before* they take it in. Bacteria secrete digestive enzymes out through their walls. Food materials are broken down into simple form by these enzymes. The enzymes also make the food molecules water soluble. These simple, water-soluble nutrients are then absorbed by the bacteria. As an example, imagine some saprophytic bacteria in a dead log in a forest. The bacteria secrete enzymes that digest cellulose, the main ingredient in wood. The cellulose is broken down into glucose, which is easily absorbed by the bacteria. Parasitic bacteria take glucose and other nutrients directly from their living host without having to digest them.

Two groups of bacteria can make their own food. These include the phototrophic bacteria already mentioned. The other group of bacteria that make their own food are the **chemotrophic** (ke mo träf'ik) bacteria. The chemotrophic bacteria get their energy from the breakdown of certain mineral compounds. Compounds of iron, sulfur, or nitrogen are used by bacteria in this group.

Thus, the list of conditions for bacterial growth includes moisture, darkness, proper temperature, and a suitable food source. But what about oxygen? Don't all living things require oxygen? Plants and animals require oxygen, but a good many bacteria do not. Bacteria can be placed in groups based on their need for oxygen.

1. **Obligate aerobes** (ob'lə gāt ār'ōbz) are bacteria that must have oxygen. They use it in cellular respiration, as plants and animals do. The bacteria that cause tuberculosis and diphtheria are obligate aerobes.

2. **Obligate anaerobes** (an ār'ōbz) are bacteria that can grow only in the absence of oxygen. The genus **Clostridium** includes many species of bacilli that live in the soil. They are all obligate anaerobes. These normally harmless bacteria become highly pathogenic if they get into human tissues or poorly sterilized canned food. Bacilli of the *Clostridium* genus are responsible for tetanus, gangrene, and a deadly type of food poisoning called botulism.

3. **Facultative** (fak'əl tã tiv) **anaerobes** are bacteria that grow with or without oxygen. The majority of bacteria are in this group. It includes *E. coli* and other intestinal bacteria.

Some groups of bacteria have the ability to use nitrogen gas (N_2) from the atmosphere. They convert it to ammonia (NH_3) or to a **nitrate**, a substance that contains a nitrogen atom combined with three oxygen atoms. This process is called **nitrogen fixation** (nī trə jən fik sã'shən). Nitrogen fixation by bacteria provides the soil with nitrates for plants to use. The plants use the nitrates to make proteins. Animals, in turn, get their protein from plants. In short, the whole living world depends on nitrogen-fixing bacteria as a source of usable nitrogen.

14–5 Reproduction by bacteria Bacteria increase their numbers by an asexual division process called **binary** (bī'nər ē) **fission**. *Binary fission* means “splitting in two,” and it is a simpler process than mitosis. The DNA in a bacterial cell makes two copies of itself. One copy is for each daughter cell, just as in mitosis. The other features of mitosis are not seen in binary fission. There are no centrioles or spindle fibers and no visible chromo-

SCIENCE BACKGROUND

Under anaerobic conditions, nitrogen-fixing bacteria can get oxygen for metabolic purposes by reducing nitrates to ammonia.

MAIN IDEA

Bacteria reproduce by binary fission. Some bacilli form endospores that enable them to survive adverse conditions. A few bacteria are capable of sexual reproduction.

SCIENCE BACKGROUND

During binary fission the two new chromosomes each attach to the plasma membrane at opposite sides of the dividing cell. It may be that growth of the membrane serves to pull the two copies of the chromosome apart.

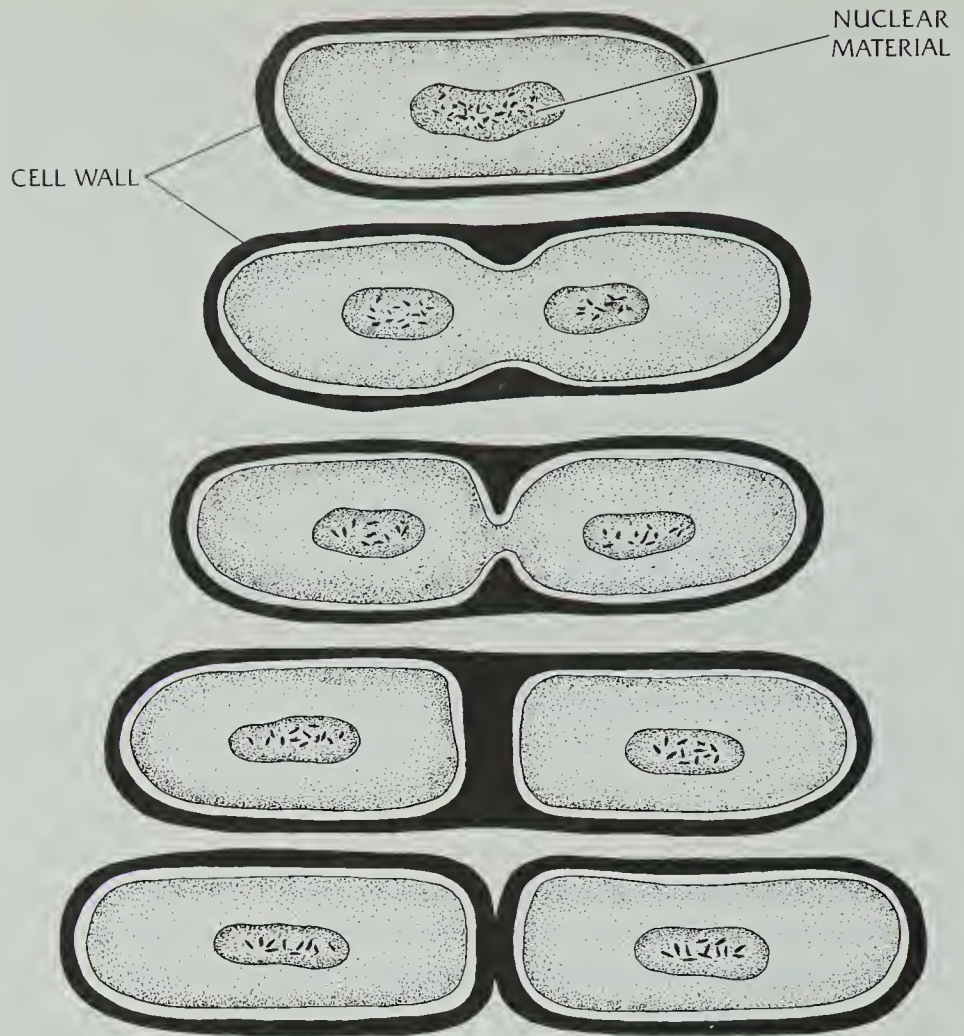
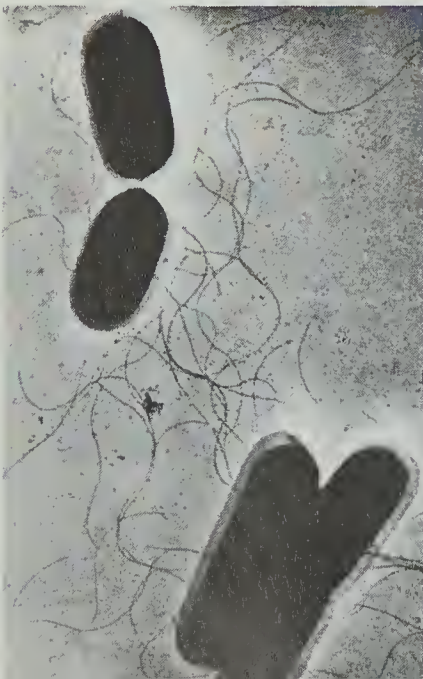


FIGURE 14-3 Asexual reproduction in bacteria is accomplished by a process called binary fission.

The top two cells in the photograph below are in the final stages of binary fission.



somes. The nuclear area just seems to split in two. The cell wall then pinches in between the two nuclear areas, and two new cells are formed.

Bacteria of the bacillus-type sometimes form resting structures called **endospores** (en'dō spôrz). The prefix *endo-* means that the spore forms *inside* a bacterial cell. The nuclear material separates into two masses, as it does in binary fission. But instead of being divided into two cells, a new wall forms around one of the nuclear areas. This wall, or spore coat, becomes thickened and is difficult to penetrate. The spore coat is made of material that is different from that of the cell wall. When the spore is fully formed, the bacillus breaks open and the spore is set free.

Bacilli form spores when conditions in the environment are unfavorable. The spores remain inactive as long as the unfavorable conditions last. When a spore is exposed to good growing conditions, its coat breaks open. A bacillus then grows out of it.

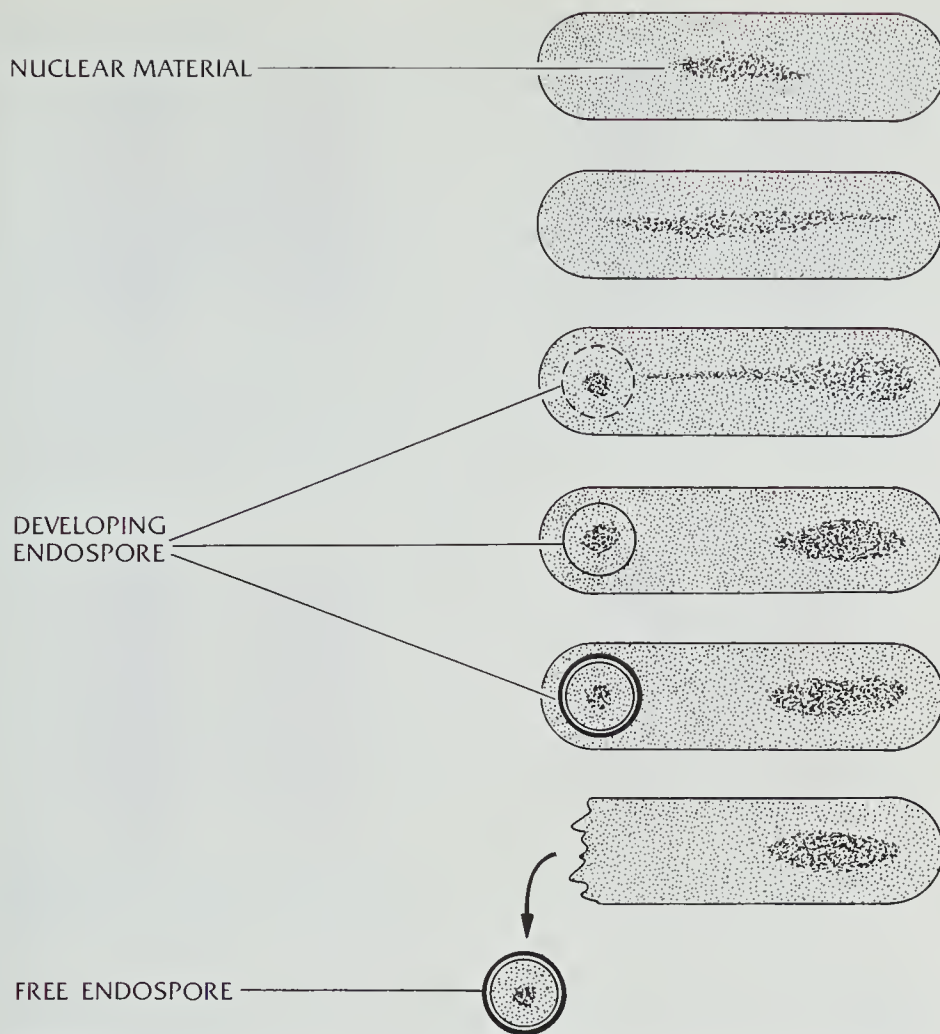


FIGURE 14-4 Some bacilli form endospores when environmental conditions are unfavorable. The spore can survive until conditions improve.

Bacteria do not increase their numbers by forming endospores. Each spore produces only a single new cell. The spores allow bacilli to survive through periods of difficulty. Spores are extremely resistant to bad conditions. They withstand drying, extremes of temperature, and chemicals that would kill an active bacillus. Spores that had been trapped within the ice of glaciers for thousands of years have been made to grow in the laboratory. Some spores can even survive an hour in boiling water. Therefore boiling is not a sure way of killing all bacteria.

It is the spores of bacilli that make it so difficult to completely sterilize canned food. It requires steam under pressure at 121°C for at least 15 min to be sure that all spores are killed. Dry heat at 160°C for 2 h is also enough to sterilize things.

Bacteria reproduce asexually by fission. It had long been thought that this is the only way bacteria can reproduce. But in 1946 it was discovered that a few bacteria can also

SCIENCE BACKGROUND

Sterilization of liquids is now widely done by filtration. Development of membrane filters with uniform porosity as small as 0.1 micron has made this possible. Filtration is the preferred method for sterilizing beverages, because heat sterilization alters flavors.

SCIENCE BACKGROUND

Investigation of sexual reproduction in *E. coli* has led to mapping of its chromosome. By breaking the conjugation bridge before the chromosome transfer is complete and by observing which traits have been transferred and which have not, the relative position of genes on the chromosome is determined. Several hundred genes have been located on the map.

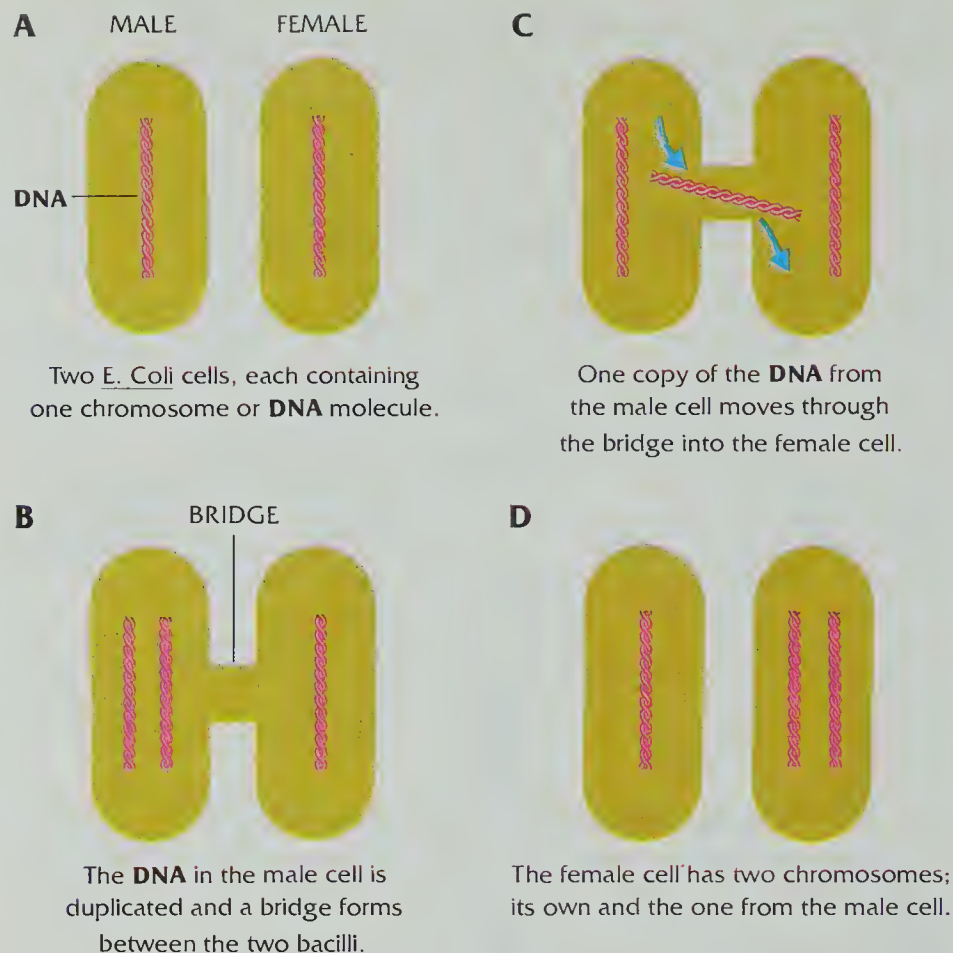


FIGURE 14-5 Sexual reproduction in bacteria involves the transfer of a chromosome from one cell to another.

reproduce sexually. *Escherichia coli*, the intestinal bacillus, exists in two mating types. These are sometimes called male and female, just for convenience. Figure 14-5 shows how these cells mate. A chromosome is passed through a bridge from a male to a female cell. The female cell ends up with two chromosomes. Later, when this cell undergoes binary fission, its daughter cells will have only one chromosome. But each may have some new combination of genetic traits. Genes from the original male and female cells may be recombined in the daughter cells.

How fast do bacteria multiply? That depends on the temperature and the type of bacteria. *E. coli* can divide once every 15 to 20 min in a liquid culture at 37°C. Other bacteria take up to several hours between divisions. The majority take an hour or less in good conditions.

If a single *E. coli* cell is placed in a broth culture, the number of cells will double every 20 min—1, 2, 4, 8, 16, . . . 4 096 after 4 h, . . . 2 million after 7 h, . . . 1 000 million after 10 h. If this rate of division continues, there will be more than a billion times a billion cells after 20 h. Can

SCIENCE BACKGROUND

In addition to a chromosome, bacteria sometimes have small extra pieces of DNA. These are called plasmids. They carry a few extra genes not necessary for survival. Genes for antibiotic resistance are carried on plasmids. Transfer of plasmids from one organism to another is one of the methods used in genetic engineering research.

this really happen? No, it is not possible. After a few hours the bacteria start to crowd each other in the culture. They begin to run out of food. Growth slows down and then stops.

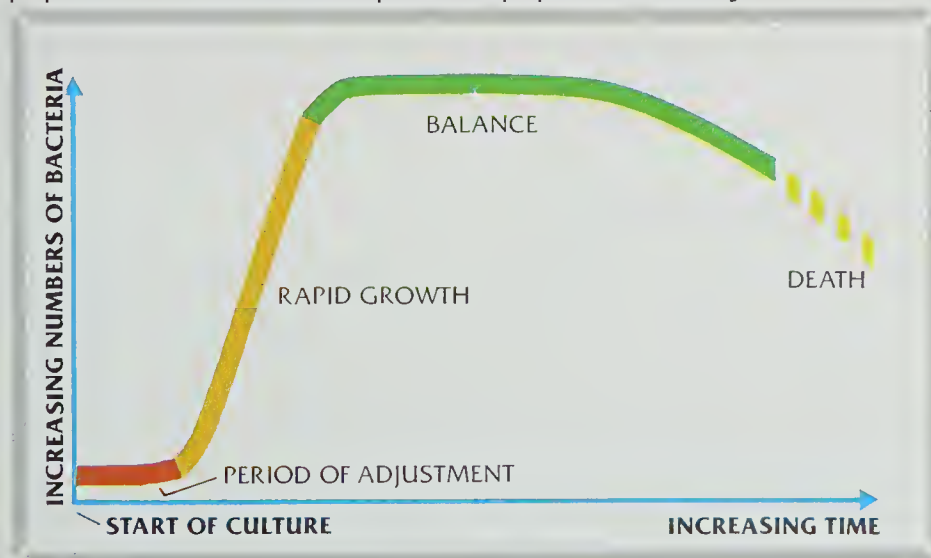
When bacteria are first placed in a fresh tube of broth, it takes some time for them to adjust to new conditions. Growth is slow at first; few cells divide. After adjusting, cells begin to divide regularly. The number of bacteria increases very rapidly. But after a while, competition for food and crowding cause growth to slow down again. Some bacteria begin to die, and a balance is reached. The number of new bacteria forming is in balance with the number of bacteria dying. This balance may last for quite some time. But the balance is finally lost. Accumulation of wastes in the culture will cause more and more cells to die. The number of bacteria decreases steadily until the whole culture dies out. Moving a few bacteria to a fresh tube of broth will start the whole cycle over again.

But isn't all this artificial? Do bacteria in nature grow as they do in test tubes? Many biologists think that the growth pattern in the test tube is similar to growth in nature. Imagine a dead leaf falling into a puddle. A few bacteria settle into the puddle from the air. After adjusting to their new surroundings the bacteria grow rapidly. They use the food provided by the dead leaf. Later the food begins to run out and the bacteria die off. Maybe some of the bacteria will form spores. The puddle dries up, and the spores are blown away by the wind. If they settle in a favorable environment, the process will start again.

SCIENCE TERMS

bacteriology
fermentation
pasteurization
Gram stain
gram-positive
gram-negative
culture
culture medium
agar
petri dishes
cocci
bacilli
spirilla
capsule
motile
phototrophic
saprophytes
chemotrophic
obligate aerobes
obligate anaerobes
facultative anaerobes
nitrate
nitrogen fixation
binary fission
endospores
mycoplasmas
rickettsias

FIGURE 14-6 The growth curve of a bacterial population indicates that population decline follows a period of population stability.



SCIENCE BACKGROUND

The graph is referred to as a standard growth curve. It is thought to apply to bacteria and to many other organisms when they are introduced into a new environment. In an open environment the curve stops when it reaches equilibrium. The formal terms for the phases of the curve are *lag phase*, *logarithmic growth phase*, *stationary (or equilibrium) phase*, and *death phase*.

MAIN IDEA

Mycoplasmas and rickettsias are procaryotic cells smaller than bacteria. Mycoplasmas lack a cell wall. Rickettsias are obligate parasites.

SCIENCE BACKGROUND

Mycoplasmas were first isolated from a pneumonia-type disease in humans and are also known as *pleuropneumoniae* organisms, or PPLO's.

SCIENCE BACKGROUND

Some bacteriologists believe that mycoplasmas are bacteria that have permanently lost their cell walls. Treatment of bacteria with antibiotics sometimes causes them to grow without walls. These are called L-cells or bacterial protoplasts and are similar to mycoplasmas.

ANSWERS TO CHECK YOUR FACTS

1. Leeuwenhoek.
2. 1850s.
3. The Gram stain.
4. Agar.
5. Larger than viruses but much smaller than plant and animal cells.
6. Bacilli.

MAIN IDEA

Blue-green algae are photosynthetic procaryotic organisms more similar to bacteria than to plants. Some can fix nitrogen.

14-6 Relatives of the bacteria There are two groups of microbes that are closely related to the bacteria but yet a bit different. **Mycoplasmas** (mī kō plaz'məz) are very small procaryotic cells. They are smaller than bacteria. Some are as small as the largest viruses. In fact, mycoplasmas were long thought to be viruses because they are so small. However, the electron microscope has shown that the mycoplasmas are true cells. They are now classified with the bacteria.

Mycoplasmas resemble bacteria in most respects. They have a plasma membrane, a cytoplasm with ribosomes, and a nuclear area, but they have no cell wall. The absence of a cell wall makes them highly variable in shape. One species causes a pneumonialike disease in humans.

Another group of bacterial relatives are the **rickettsias** (ri ket'sē əs). They are named after Howard Ricketts, who discovered them in 1909. He showed that rickettsias are the cause of Rocky Mountain spotted fever and epidemic typhus. Rickettsias are between mycoplasmas and bacteria in size. Except for their small size, rickettsias are very similar to bacteria in structure. They are cellular and they reproduce by binary fission. All known rickettsias are parasitic. Like viruses, they can only reproduce within living cells. Rickettsias can infect the tissues of many warm-blooded animals. They are spread from host to host by insects, such as lice and ticks.

CHECK YOUR FACTS

1. Who gave the first scientific description of bacteria?
2. When did Pasteur start doing experiments with bacteria?
3. What is the most widely used staining method for bacteria?
4. What is used for making solid culture media?
5. How big are bacteria?
6. What types of bacteria form endospores?

Blue-Green Algae

14-7 Characteristics of blue-green algae

Blue-green algae are named for their pigments. All blue-green algae contain chlorophyll, which is green, and **phycocyanin** (fī kō sī'ə nin), which is blue. Some blue-green algae also contain red or yellow pigments in addition. These algae appear in almost every color of the rainbow. The color of any given species depends on how much of each pigment is present. The Red Sea got its name from a

blue-green alga. This blue-green alga is red and it grows in huge numbers at some times of the year.

The cells of blue-green algae are much like the cells of other monerans. Blue-green algae cells have one special feature. These are the **photosynthetic** (fō tō sin the'tik) **membranes** that are found around the edges of the cell. The photosynthetic membranes arise from inward foldings of the plasma membrane. The enzymes needed for photosynthesis are located on these membranes. The membranes are not the same as chloroplasts, which are found only in eucaryotic plant cells. In addition to photosynthesis, some blue-green algae are capable of nitrogen fixation. This activity makes nitrates available to other water plants.

The cytoplasm of blue-green algae contains ribosomes, starch granules, and nuclear material in the central area. The starch granules are food reserves. The cell walls of blue-green algae are chemically similar to those of bacteria. They are not like the cell walls of plants. Blue-green algae reproduce only by binary fission. Sexual reproduction has not been observed in any of these algae.

Some blue-green algae are unicellular, but most form colonies. Colonies may take the form of spheres, flat sheets, or threads. The threadlike colonies, or **filaments** (fil'ə mōnts), are the most common form. When the cells in a filament divide, they remain attached to each other. This causes the filament to grow longer. The cells in a filament secrete a substance like mucus. This material forms a **sheath** around the colony.

A number of blue-green algae form resistant spores. These are not the same as endospores, but they serve the same purpose. They form from whole cells, rather than inside of a cell. These spores also have thick walls and can survive through harsh conditions. Blue-green algae also form **heterocysts** (het'ər ə sists). The function of heterocysts is not clear. In some filaments the heterocysts seem to serve as weak points where the filament can break. When a filament gets too long, it breaks into sections. Each section then grows into a new filament. Water currents and the movement of fish break the filaments and move them around. This is how blue-green algae can quickly spread through a pond.

14-8 Blue-green algae in nature Blue-green algae are among the hardiest of living things. They can actively grow where bacteria only survive as spores. Although blue-green algae are most common in ponds, some species can be found almost anywhere there is mois-

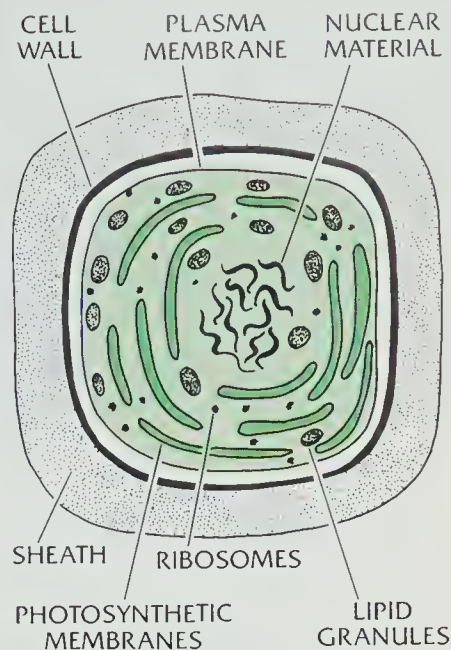


FIGURE 14-7

In blue-green algae, photosynthesis occurs on photosynthetic membranes. In higher algae and plants, photosynthesis occurs in chloroplasts.

SCIENCE TERMS

phycocyanin
photosynthetic membranes
filaments
sheath
heterocysts

SCIENCE BACKGROUND

The ability of blue-green algae to fix nitrogen is thought to contribute to the fertility of rice paddies. Nitrates produced by the blue-green algae stimulate growth of the rice plants.

MAIN IDEA

Blue-green algae are extremely hardy and grow wherever there is sufficient moisture.



SCIENCE BACKGROUND

Some biologists believe that the monerans represent the origin of mitochondria and chloroplasts in eucaryotic cells. Bacteria resemble mitochondria in that they have respiratory membranes on the inside of their plasma membrane. Blue-green algal cells are similar in structure to chloroplasts. It is theorized that a primitive ameoboid cell might have engulfed some bacteria and some blue-green algae and retained them in a symbiotic relationship. This idea is supported by the fact that mitochondria and chloroplasts have their own DNA and reproduce themselves during mitosis.

ANSWERS TO CHECK YOUR FACTS

1. Photosynthetic membranes.
2. All colors.
3. Bacteria.
4. 80°C.
5. Fresh water, salt water, damp rocks, damp soil.
6. No.

Anabaena (left) and Spirulina (right) are blue-green algae that grow as filaments.

ture. Some species live in snow; others live in hot springs at temperatures as high as 80°C. The beautiful, multi-colored growths of these algae in the hot springs of Yellowstone National Park, Wyoming, attract many visitors.

Blue-green algae also live in the sea. Saltwater types also live on shoreline rocks where they are kept damp by spray from the surf. Others can be found in damp soil or where rocks are splashed by waterfalls. The sheath helps to keep blue-green algae from drying out when they are not in the water. Blue-green algae can sometimes be seen on the soil of flowerpots that are kept too moist.

Blue-green algae grow best in warm lakes or ponds that have a lot of dead organic matter in them. They tend to grow in water reservoirs in the summer. The algae give an “earthy” taste to the drinking water. Chlorine is added to the water to eliminate these algae and other microbes.

Some types of pollution, such as human wastes and detergents in household sewage, cause increased growth of algae. The organic matter in these wastes serves as food for the algae. The blue-green algae are the first to react to this type of pollution. Biologists sometimes measure the pollution in a lake by counting the number of blue-green algae in the water. *Oscillatoria* is one genus that is counted for this purpose. *Oscillatoria* also has another interesting feature. Its filaments move from side to side, or oscillate, in the water. That is how the alga got its name. It is not known what causes the motion. Blue-green algae do not have flagella.

The filaments of blue-green algae are microscopic. With favorable growth conditions they accumulate in large, floating masses. Heavily polluted lakes or small ponds with much decaying matter are sometimes covered over by these matlike growths of blue-green algae.

CHECK YOUR FACTS

1. What structure is found in blue-green algae but not in bacteria?
2. What color are blue-green algae?
3. Do the cell walls of blue-green algae most resemble the walls of bacteria or the walls of plants?
4. What is the highest temperature at which blue-green algae have been found living?
5. Where do blue-green algae live?
6. Are flagella found in blue-green algae?

SUMMARY

Bacteria and blue-green algae are procaryotic. They exist as unicellular organisms and as colonies. Bacteria are the phylum Schizomycetes and the blue-green algae are the phylum Cyanophyta. Together, these two phyla form the kingdom Monera. Bacteria are larger than viruses. They can be seen with a light microscope and can be grown in culture. Because of this, bacteria were identified and studied over a century ago. Bacteria exist in many shapes and they vary a great deal in their metabolism.

REVIEW QUESTIONS

1. How are colonies of organisms different from multicellular organisms?
2. What did Louis Pasteur discover about fermentation?
3. What is fermentation?
4. What are four different ways in which bacteria get their nourishment?
5. What conditions do most bacteria require for growth?
6. What is the purpose of endospores?
7. Why were mycoplasmas first thought to be viruses?
8. How rapidly do bacteria multiply?
9. How did blue-green algae get their name?
10. What group of monerans consists only of parasites?

ANALYSIS AND APPLICATION

1. Is pasteurization the same thing as sterilization?
2. Why is nitrogen fixation so important?
3. Why are mycoplasmas and rickettsias included in the kingdom Monera? Why are they classified with the bacteria?
4. What factors cause growth to slow down and stop in a bacterial culture?

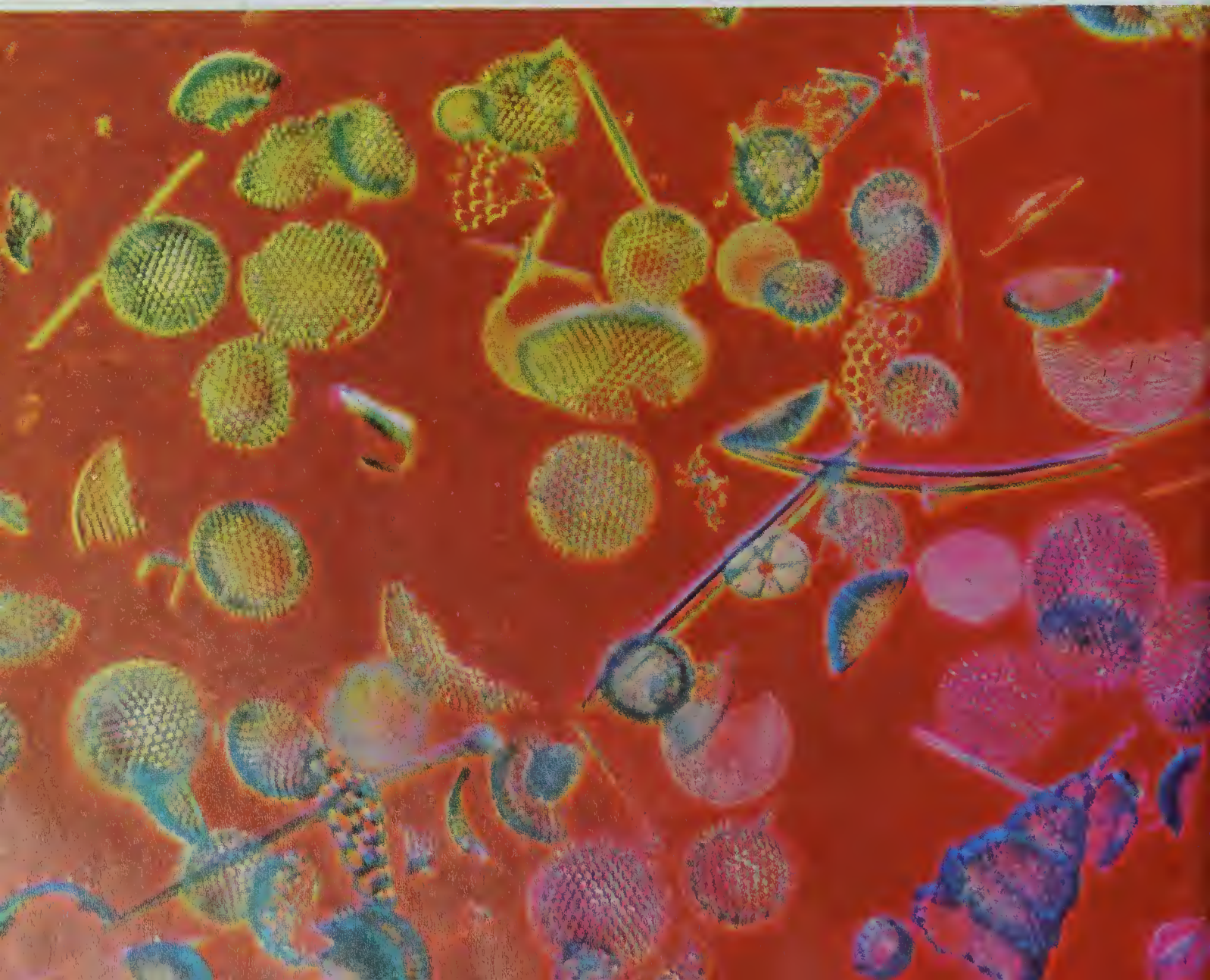
ANSWERS TO REVIEW QUESTIONS

1. The cells in colonies are independent of each other.
2. That fermentation is caused by microbes. Each species causes a different type of fermentation.
3. The splitting of sugars for energy in the absence of oxygen.
4. Parasitism, saprophytism, chemotrophism, and phototrophism.
5. Moisture, darkness, suitable temperature, and a food source.
6. To allow survival during adverse conditions.
7. Because of their small size and ability to pass through porcelain filters.
8. Some divide every 15 to 20 min; others take several hours.
9. They all contain a blue (phycocyanin) and a green (chlorophyll) pigment.
10. Rickettsias.

ANSWERS TO ANALYSIS AND APPLICATION

1. No. Pasteurization only stops the growth of microbes. It does not kill spores. Sterilization kills all microbes including spores.
2. Nitrogen fixation makes nitrogen available to other organisms in soluble form. The entire living world depends on this for the nitrogen needed to make proteins.
3. They are included in the kingdom Monera because they are procaryotic. Except for the lack of cell walls in mycoplasmas, these groups are generally similar to bacteria and lack the photosynthetic membranes of blue-green algae.
4. Physical crowding, competition for nutrients, and accumulation of wastes.

15 *The Protists*



OBJECTIVES

- To discuss the distinction between protozoa and protophytes
- To name the general characteristics of protozoa
- To introduce the concept of symbiosis
- To understand amoeboid motion
- To describe the characteristics of sarcodines
- To describe the characteristics of flagellates
- To describe the characteristics of *Paramecium*
- To understand sexual reproduction in ciliates
- To describe the life cycle of *Plasmodium*
- To describe the characteristics of diatoms
- To describe the characteristics of the dinoflagellates
- To describe the characteristics of *Euglena*

Protozoa: The Animallike Protists

15-1 Introduction The world around us is filled with one-celled organisms. Some of them are monerans. A great many others are one-celled members of the **kingdom Protista** (prō tis'tə). Most members of this kingdom are single-celled. Some form colonies or filaments. All have eucaryotic cells. (Remember, the kingdom Monera contains organisms that are unicellular and *procaryotic*.) The organisms of the kingdom Protista are called **protists** (prō'tists).

The protists were first discovered by Leeuwenhoek in 1675. Since then many varieties of protists have been found. No one knows exactly how many kinds there are. There are probably more than 60 000 different species. Many make shells with beautiful patterns on them. A few protists are parasites, but most of them are free-living. They are found everywhere there is water, from puddles to oceans.

The smallest protists are about the size of bacteria. Others are much larger. The largest unicellular protists grow to a size of 3 mm. Imagine a single cell that large! The larger protists can be seen with the naked eye.

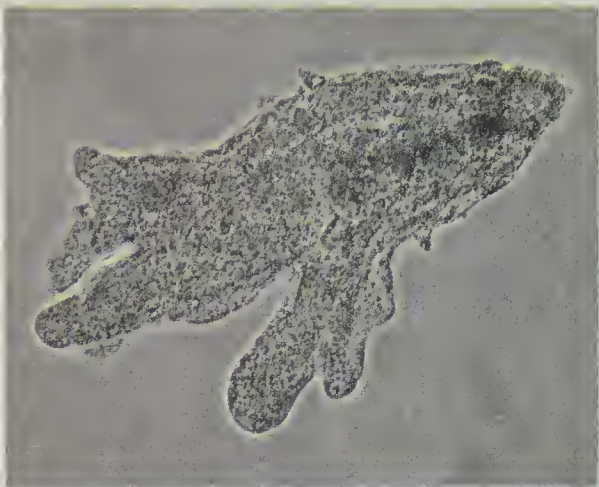
For years many protists were classified as animals. They were placed in a group called the phylum Protozoa (prō tə zo'ə). Then biologists came to realize that some protists are more like plants than animals. These protists have chloroplasts and use them in photosynthesis. Because of the combination of animal and plant characteristics, the protists have now been placed in a kingdom of their own.

MAIN IDEA

The kingdom Protista contains a wide variety of eucaryotic, unicellular, and colonial organisms. Some have animallike characteristics and some have plantlike characteristics.

SCIENCE BACKGROUND

Mixed cultures of protists are easily established in the classroom. This is valuable in demonstrating that the cysts of protists are airborne. Place some hay or some shredded lettuce in a large glass container. Cover with boiling water and leave standing in a warm, dimly lit area. Within a few days bacterial decay should be evident. After three or more weeks, protists will have established themselves by feeding on the bacteria.



Some protists, such as the amoeba, are more like animals than like plants and are often referred to as protozoans.

There are seven phyla in the kingdom Protista. Four of these phyla contain organisms that are more like animals than plants. These are still referred to by the old name, **protozoa**, which means “first animals.” The plantlike protists in the other three phyla are called **protophytes**.

The animallike protists, or protozoa, are almost as hardy as the blue-green algae. They live in salt water, fresh water, damp soil, and inside large plants and animals. A few species of protozoa can live in both fresh water and salt water. Protozoa are among the few organisms that can grow in Great Salt Lake in Utah. Some protozoa live at temperatures of 60°C, but most prefer temperatures between 10°C and 25°C. They are easily killed by freezing.

The majority of protozoa are **holozoic** (hol ə zō'ik). This means that they eat solid food particles, as most animals do. Bacteria are their favorite food. They also eat unicellular algae and other microbes. The holozoic types live in ponds, lakes, and the ocean. Some swim near the surface, eating algae. Others crawl around the bottom, eating bacteria and bits of dead organic matter.

Other protozoa are **saprozoic** (sap'rə zō'ik). They absorb soluble nutrients through their cell membranes. The remaining protozoa are **parasites** (par'ə sīts). Parasites live in or on the body of another organism and obtain nourishment from that organism.

All protozoa can reproduce by fission. Many of them also engage in sexual reproduction. Some forms have complex life cycles that require both sexual and asexual reproduction to produce a new generation. It is the parasitic protozoa that are most likely to have these complex life cycles.

Many protozoa are involved in **symbiosis** (sim bī ō'sis). *Symbiosis* is a Greek word that means “living together.” It is a relationship between two organisms of different kinds. Both organisms may benefit from living together. An example is the relationship of certain protozoa that live in the stomach of cows. Cows cannot digest the cellulose in the plants they eat. The protozoa in a cow's stomach help to complete this task. In return, they get a warm, moist place to live and a steady supply of food.

Some protozoa carry small unicellular algae inside their cytoplasm. This is another example of symbiosis. The protozoa are holozoic and the algae are photosynthetic. Both can live in a wide variety of conditions because they share their food with each other.

Protozoa survive harsh conditions by forming **cysts** (sists). Cysts are similar to spores that are formed by blue-green algae. When a protozoan is going to form a cyst, it first stores food in its cytoplasm. The protozoan loses water

and rounds up like a ball. It then forms a thick, tough wall around itself. Protozoans most often form cysts when there is drought or when it is too hot or too cold.

Protozoan cysts can live for many years. They can be spread around by wind or water currents. Cysts are carried from place to place on the feet of birds and other animals. Because they spread so easily, the same types of protozoa are found everywhere. A nearby pond might have the same kinds of protozoa as a pond on the other side of the world.

15-2 Phylum Sarcodina The simplest protozoa are the genus *Amoeba*. These formless creatures represent the **phylum Sarcodina** (sär kō dē'nə). They have often been called living blobs of jelly. Amoebas have no covering outside their plasma membrane. They are flexible and constantly change their shape. If you watch a living amoeba under a microscope, you will see that the cytoplasm is constantly moving.

The cytoplasm of amoebas and other protists has two parts. The **ectoplasm** (ek'tə plaz əm) forms a thin layer under the plasma membrane. It is like jello that has become old and stiff. The **endoplasm** (en'dō plaz əm) fills the interior of the cell. Endoplasm is like fresh jello that has not set. It is more fluid than the ectoplasm and can move about freely.

Amoebas move by forming projections known as **pseudopodia** (sü də pō'dē ə), or false feet. The endoplasm streams toward the plasma membrane. It causes a bulge to move forward. The bulge grows larger as more

MAIN IDEA

The phylum Sarcodina encompasses the protozoa that move by pseudopodial action. These include amoebas, which are naked, and the *Foraminifera* and *Radiolaria*, which have shells.

SCIENCE BACKGROUND

A number of amoebas are found in the human intestine. *Entamoeba coli* is a harmless symbiont. *Entamoeba histolytica* is a related pathogenic species, which is the cause of amoebic dysentery.

FIGURE 15-1

The cellular structure of a typical amoeba is shown in the illustration below.

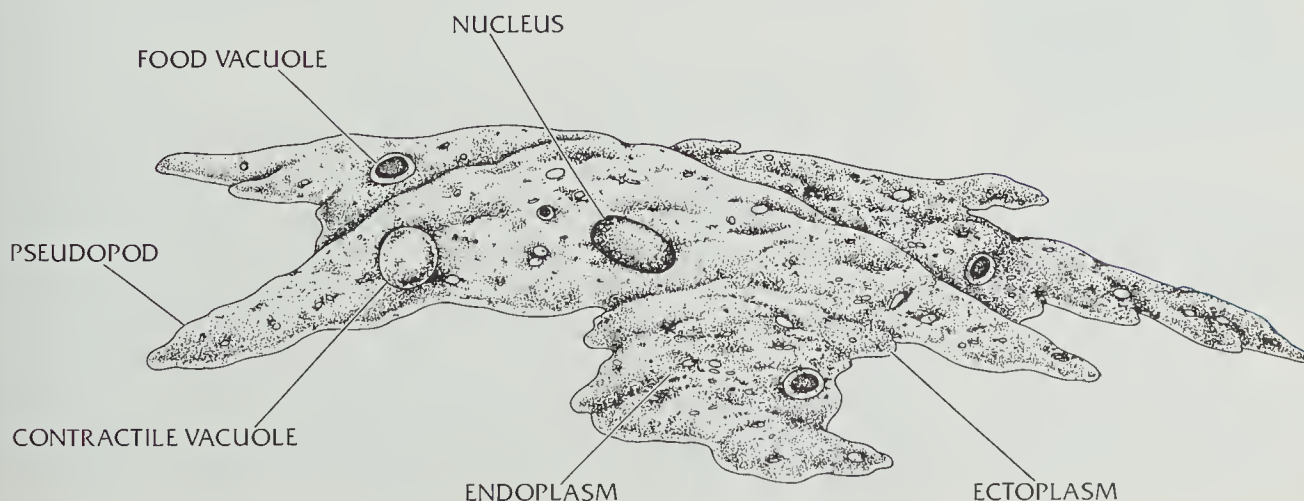




FIGURE 15-2

In amoebas, pseudopodia are used both for movement and for the capturing of food.

endoplasm flows into it, forming a pseudopodium. Soon a second pseudopodium will begin to form as the endoplasm from the first one flows back into the main area of the cell. The new pseudopodium enlarges and draws the amoeba forward. The amoeba moves by forming one pseudopodium after another.

This pattern of locomotion is known as **amoeboid** (ə mē'boïd) **motion**. Amoebas are not the only cells that move this way. The white blood cells of animals use amoeboid motion to wander through the body in search of infectious microbes.

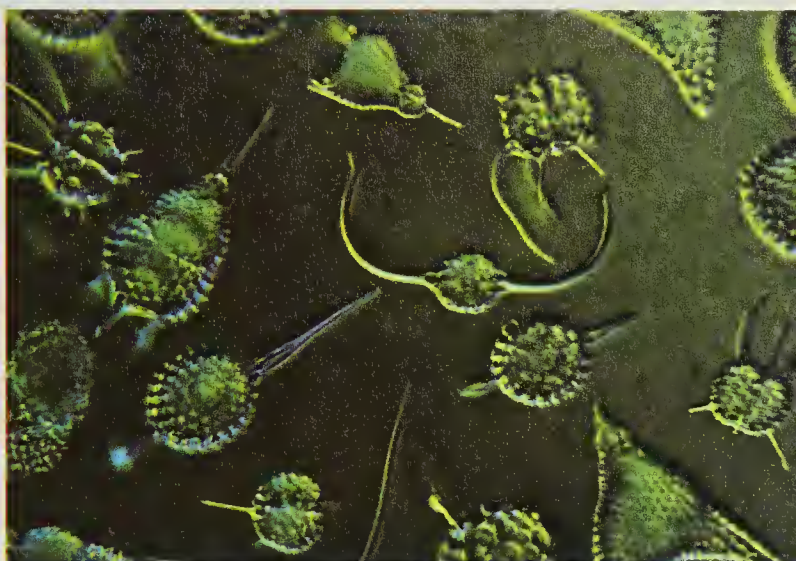
Amoebas also use pseudopodia to get their food. Two pseudopodia surround a food particle and draw it into the cytoplasm. This is the process of phagocytosis. Amoebas eat mostly live food. Their diet consists of bacteria, algae, and even protozoa, which are smaller than themselves. During phagocytosis, food particles are enclosed within a **food vacuole** in the cytoplasm. The lysosomes in the cytoplasm join with the food vacuoles and release enzymes that digest the food. The digested food substances pass through the membrane surrounding the vacuole.

Amoebas constantly absorb water from their surroundings. Water enters the amoeba by diffusion, and some is taken in along with food during phagocytosis. The amoeba must have some way of ridding itself of extra water. If it did not, it would swell up and burst. Extra water is accumulated in a **contractile** (kən trak'təl) **vacuole**. When this vacuole becomes full, it contracts. The water is pushed out through a pore in the plasma membrane. Think of squeezing water out of a rubber bulb. That is how the contractile vacuole works.

Amoebas can sense changes in their environment. They detect light and move away from it. They prefer darkness, as do the bacteria that are their food. Amoebas can sense the difference between food particles and other solid objects. They move toward food but away from all other objects. Amoebas can also sense dryness or cold. They respond to these conditions by forming cysts.

The phylum Sarcodina includes two groups of amoeba-like protists, which form shells. The shells of these creatures are among the most beautiful things in nature. *Radiolaria* (rā dē ō lār'ē ə) form shells of a material called silica. Silica is very much like glass. There is an opening in the shell through which the radiolarian puts out its pseudopodia.

Another group with shells are the *Foraminifera* (fə ram ə nif'ər ə). The shells of these organisms are composed of a chalky substance and usually have many chambers. As fo-



Foraminiferans grow they add new chambers to their shells. Each new chamber is larger than the old ones. There are openings in the walls of the chambers. This allows the cytoplasm to occupy all the chambers.

Radiolarians and foraminiferans live in the upper layers of the ocean. Billions of them grow and die each year. When they die, their shells fall to the bottom of the ocean. Sometimes these shells are preserved in rock and become fossils. Fossil foraminiferan shells have been found in rocks that are almost 2 thousand million years old. This is the earliest clear evidence of eucaryotic cells on earth.

15-3 Phylum Mastigophora Protozoa that move about by means of flagella are placed in the **phylum Mastigophora** (mas tə gəf'ər ə). *Mastigophora* means "whip bearers" and refers to the action of the flagella. The organisms in this group are called **flagellates** (flaj'ə lāts). These organisms may have one or several hundred flagella. The flagellates are thought to be the oldest group of protists. Some biologists believe that ancient flagellates were the ancestors of the sponges.

Flagellates do not change their shape as amoebas do. They keep their shape because of a covering layer called the **pellicle** (pel'ə kəl). A pellicle is neither a cell wall nor a shell. It is formed by a thickening of the outer layer of the plasma membrane. Pellicles are not hard, but they are firm enough to help cells keep their shape.

Only a few of the flagellates are free-living. Most of them live within other organisms. Some are parasites, but many have other relationships with their host. One type lives in the intestines of termites. Termites are completely unable to digest wood by themselves. They depend on the fla-

The shells of foraminiferans are multi-chambered (left). The shells of radiolarians are composed of silica, which is similar to glass.

SCIENCE BACKGROUND

Each species of *Foraminifera* has a preference for a certain water temperature. Examination of foraminiferan remains in various geologic strata has yielded information on the climate of past geologic eras.

MAIN IDEA

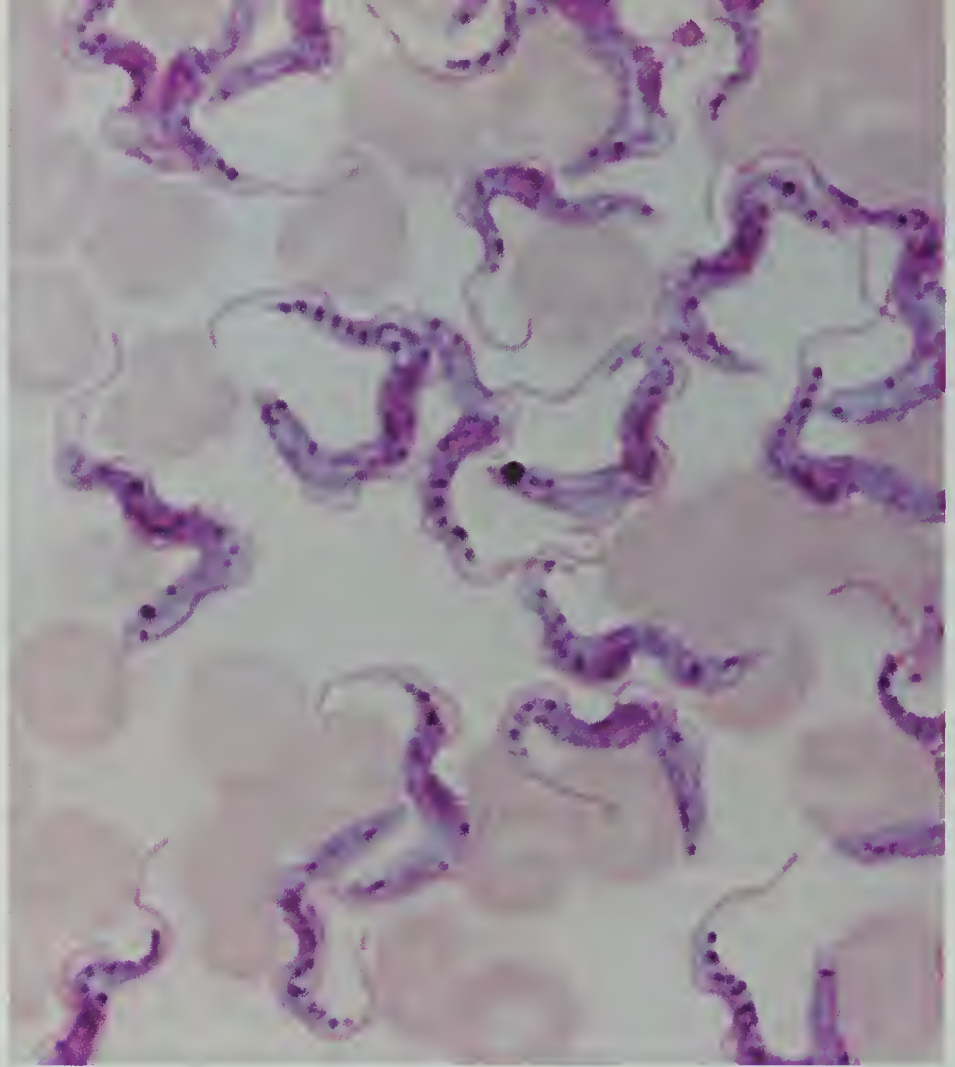
The phylum Mastigophora includes the protozoa that move by flagellar action. Few are free-living; most are symbionts or parasites.

SCIENCE BACKGROUND

Termites lose their flagellated symbionts each time they molt. They cannot survive without the wood-digesting activity of these protists; therefore they must ingest a fresh supply of flagellates from the feces of other termites after each molt.

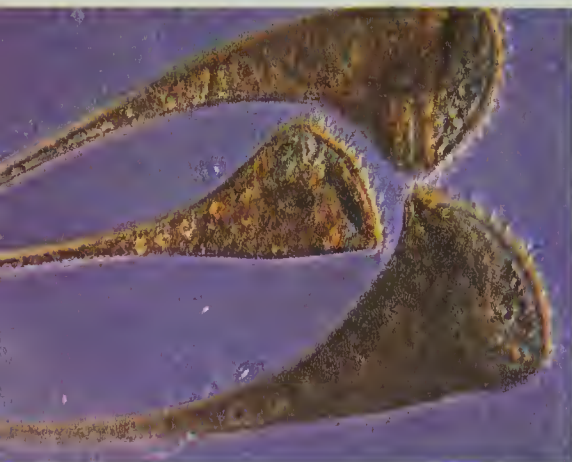
SCIENCE BACKGROUND

Flagellates are regarded as the central group of protists, perhaps the progenitors of other protists and of higher plants and animals. Some amoebas, ciliates, and sporozoa with complex life cycles pass through flagellated stages before adulthood. Higher animals and plants often produce flagellated gametes.



Trypanosomes, flagellated protists, can be seen among the blood cells in the photograph above. Sleeping sickness is caused by these organisms.

Stentor, a ciliated protist, is trumpet-shaped. When feeding, its narrow end is attached to a plant or rock in the water.



gellates to do the job. A termite will die if it loses its flagellates. Maybe someone will think of a way to get rid of these pests by getting rid of their flagellated partners.

Several species of flagellates are parasitic in humans. Members of the genus *Trypanosoma* (trip ə nə sō'mə) cause African sleeping sickness and a few related diseases. Trypanosomes infect the blood, liver, and brain.

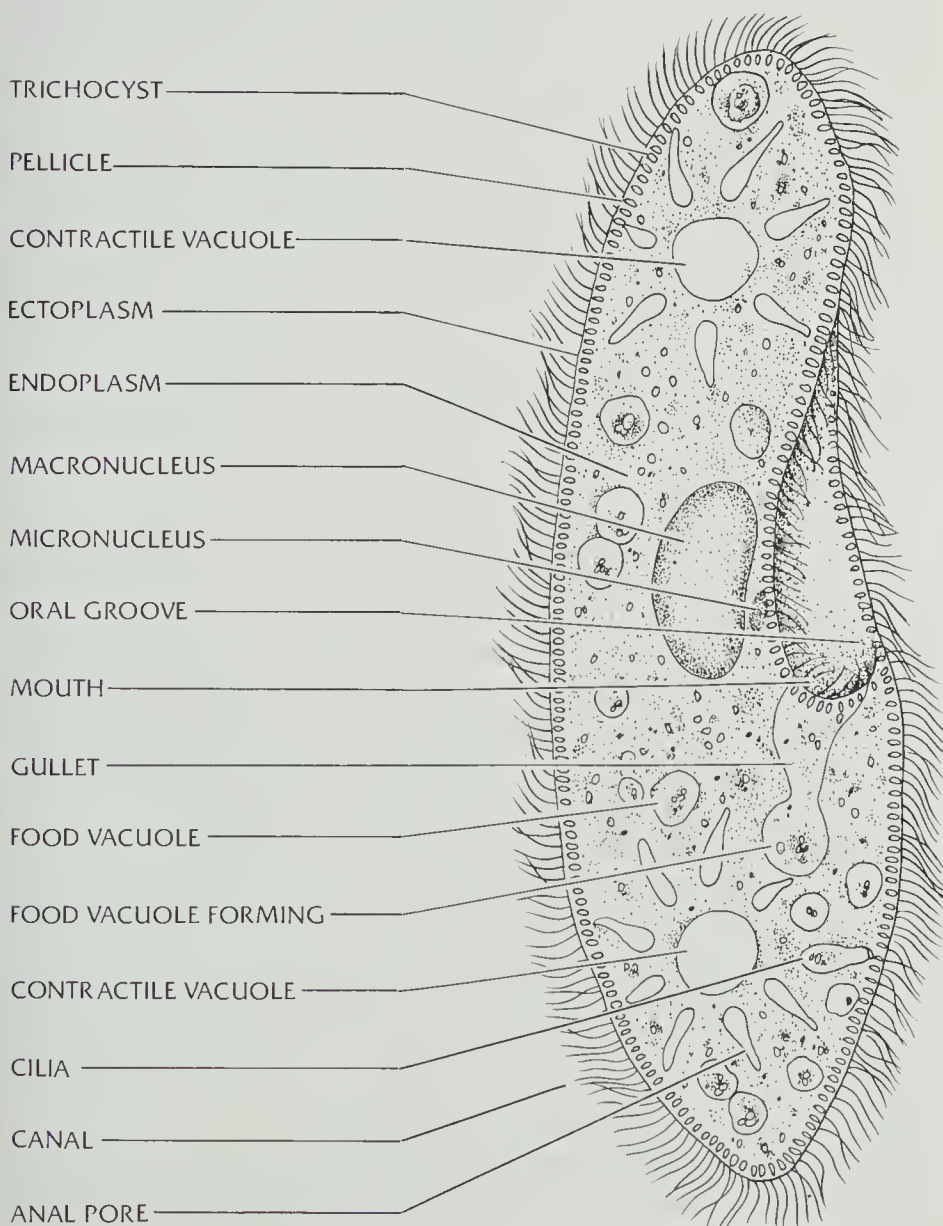
Flagellates differ from other groups of protists in that none of them are known to reproduce sexually. Flagellates only reproduce by fission. These organisms also form cysts. The parasitic types spread from host to host as cysts, not as adults.

15-4 Phylum Ciliophora **Cilia** (sil'ē ə) are structures like flagella that are used for movement. Cilia are shorter than flagella and are found in large numbers. A cell never has just one or two cilia. Very often cilia cover the entire surface of a cell. Protozoa that use cilia for locomotion or to gather food are called **ciliates** (sil'ē its). These protozoa are in the **phylum Ciliophora** (sil ē əf'ə rə).

Cilia can be used in two ways. They can be used for swimming by ciliates that chase after their food. Cilia can also be used by others that stay in one place and create whirlpoollike water currents that bring them bacteria and other food particles. *Paramecium* is a ciliate that swims after its food. *Vorticella* attaches itself to objects in a pond and creates a whirlpool that brings food to it.

Ciliates are the most complex of the protozoa. They usually have more than one nucleus, and they have many different organelles. Some ciliates reproduce sexually. Almost all of them are active, free-living organisms. There are few parasites in the group.

Paramecium is the best-known ciliate. It is shaped like the sole of a shoe. It has a pellicle to maintain its shape. On one side of *Paramecium* is an **oral groove**. The forward



MAIN IDEA

The phylum Ciliophora includes the protozoa that use ciliary action for locomotion or to gather food. These are the most complex protozoa.

SCIENCE BACKGROUND

The cilia and flagella of protists are essentially the same as those found in human and other animal tissues. The cilia and flagella of all groups except the Monera have the same ultrastructure. Nine longitudinal bundles of microtubules are arranged in a circle around the periphery of the cilium or flagellum. Two single microtubules run longitudinally through the center. The microtubules consist of contractile protein.

SCIENCE BACKGROUND

In some ciliates, batches of cilia are cemented together at their tips to form cirri. Ciliates that dwell at the bottom of ponds use cirri as if they were legs to walk along the bottom in search of food.

The sequence of divisions of the micronucleus in the early stages of *Paramecium* conjugation is essentially the same as in meiosis. The "male" micronuclei, which are exchanged between cells, are in a haploid condition. The micronucleus that forms by fusion of the "male" and the "female" micronuclei is essentially a zygote, even though it is still contained within the parent cell.

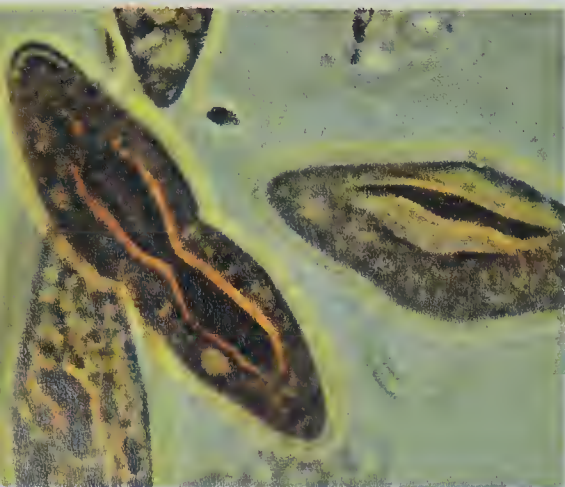
FIGURE 15-3

The structures of a *Paramecium* are identified in the illustration at left.

SCIENCE TERMS

kingdom Protista
protists
protozoa
holozoic
saprozoic
parasites
symbiosis
cysts
phylum Sarcodina
ectoplasm
endoplasm
pseudopodia
amoeboid motion
food vacuole
contractile vacuole
phylum Mastigophora
flagellates
pellicle
cilia
ciliates
phylum Ciliophora
oral groove
gullet
anal pore
trichocysts
macronucleus
micronucleus
conjugation
phylum Sporozoa

During asexual reproduction in *Paramecium*, the micronucleus divides by mitosis and the macronucleus divides by fission.



motion of the cell and the cilia in the oral groove sweep food particles into the mouth. The mouth leads into a tube called the **gullet** (gul'it), which extends into the cytoplasm. As the bottom of the gullet fills up with food, it pinches off and forms a food vacuole. The food vacuole moves away, and a new one begins to form at the bottom of the gullet.

As in the amoeba, the cytoplasm of *Paramecium* is divided into endoplasm and ectoplasm. The endoplasm moves in a circular pattern around the cell. The food vacuoles travel with it. As the food is digested the vacuole grows smaller. Any wastes remaining in the vacuole are passed out through an opening in the pellicle. This opening is called the **anal** (ā'nəl) **pore**.

Like amoebas, *Paramecium* uses contractile vacuoles to eliminate excess water. These vacuoles in *Paramecium* have the shape of a flower. They have several canals and a central vacuole. The canals bring water from all around the cytoplasm to the central vacuole. The central vacuole contracts and pushes the water out.

The cilia of *Paramecium* work like the arms of a swimmer. The cilia point straight out as they beat toward the rear. They are bent as they are brought forward to their original position again. The cilia on *Paramecium* beat in a coordinated manner. They all beat in the same direction when the *Paramecium* is swimming. All the cilia are connected to each other by fibers in the ectoplasm. It is thought that these fibers bring about the coordination of the cilia.

Paramecium can sense changes in its environment, just as amoebas can. It, too, moves away from light and solid objects other than food. But *Paramecium* can defend itself. When disturbed, *Paramecium* can shoot out many harpoonlike structures. These are called **trichocysts** (trī'kōsists), and each consists of a thread with a point, or barb, at the end. The trichocysts are normally coiled up in tiny sacs in the ectoplasm. When a larger organism approaches, the sacs open and the "harpoons" are discharged.

Paramecium has two types of nuclei. The large one, or **macronucleus** (mak rō nü'klē əs), regulates the day-to-day activities of the cell. The small nucleus, or **micronucleus** (mī krō nü'klē əs), is active during reproduction. Both nuclei divide during cell division. The macronucleus divides by fission, and the micronucleus divides by mitosis. Despite this difference, each daughter cell always receives one macronucleus and one micronucleus.

The sexual reproduction process of *Paramecium* is known as **conjugation** (kon jə gā'shən). This process

seems to be necessary to maintain the health of the organism. Paramecia can be prevented from mating and allowed to reproduce only by fission. If this is done, they begin to grow unhealthy and die after about 350 divisions. The exchange of genetic material that occurs during conjugation seems to give the paramecia new life.

Conjugation occurs in the following manner (refer to Figure 15-4):

1. Two paramecia join together along their oral groove.
2. The micronuclei divide twice, so that each cell has four micronuclei.
3. Three of the micronuclei in each cell disintegrate, leaving only one.
4. The remaining micronucleus divides again, forming a “male” and a “female” micronucleus.
5. The “male” micronucleus in each cell crosses over to the opposite cell. This is the most important step. It represents the exchange of hereditary material between the two cells.
6. The “male” and the “female” micronuclei in each cell fuse and become one.
7. The two cells separate. The fused nucleus in each cell undergoes three divisions to form eight micronuclei.
8. Four of the eight micronuclei in each cell grow into macronuclei; three others disintegrate and one micronucleus remains.
9. Each cell divides twice, forming four daughter cells, or eight daughter cells from the pair. Each of the daughter cells gets one of the macronuclei. The micronucleus in each cell divides so that each daughter cell gets one of these. Eight new paramecia have been formed. Each is a blending of the traits of the two parent cells.

15-5 Phylum Sporozoa The fourth phylum of protozoa is made up of parasites. This is the **phylum Sporozoa** (spôr ə zō'ə), whose members can infect every major group of animals. Some even infect other parasites. Many of the sporozoa require two hosts to complete their life cycle. They reproduce sexually in one host and asexually in the other. The sporozoa differ from the other protozoa in that they have no structures for locomotion. The mature forms have neither cilia nor flagella nor pseudopodia. A few types may briefly have flagella while they are maturing.

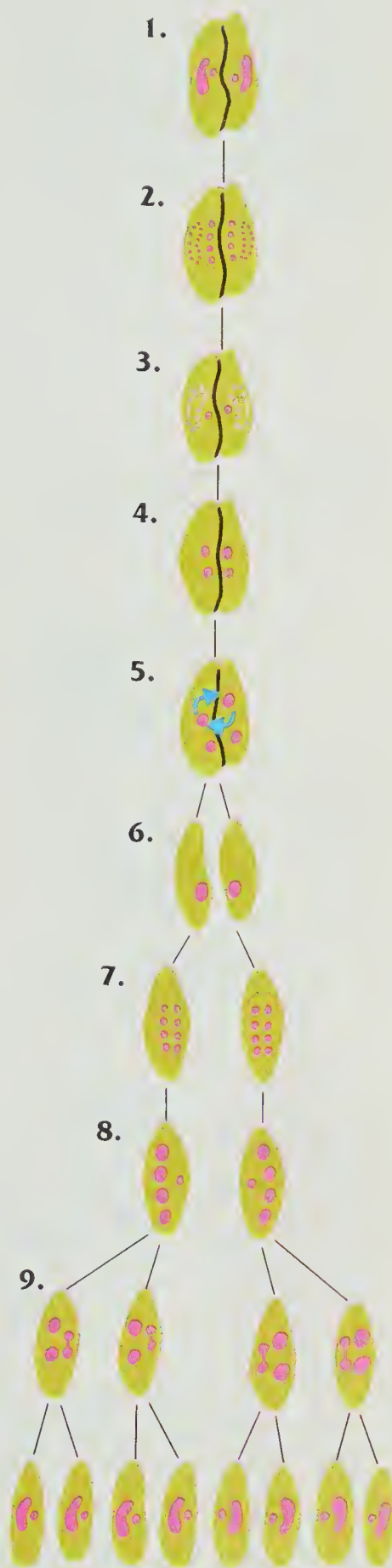


FIGURE 15-4 Sexual reproduction in *Paramecium*, known as conjugation, is illustrated at right.

MAIN IDEA

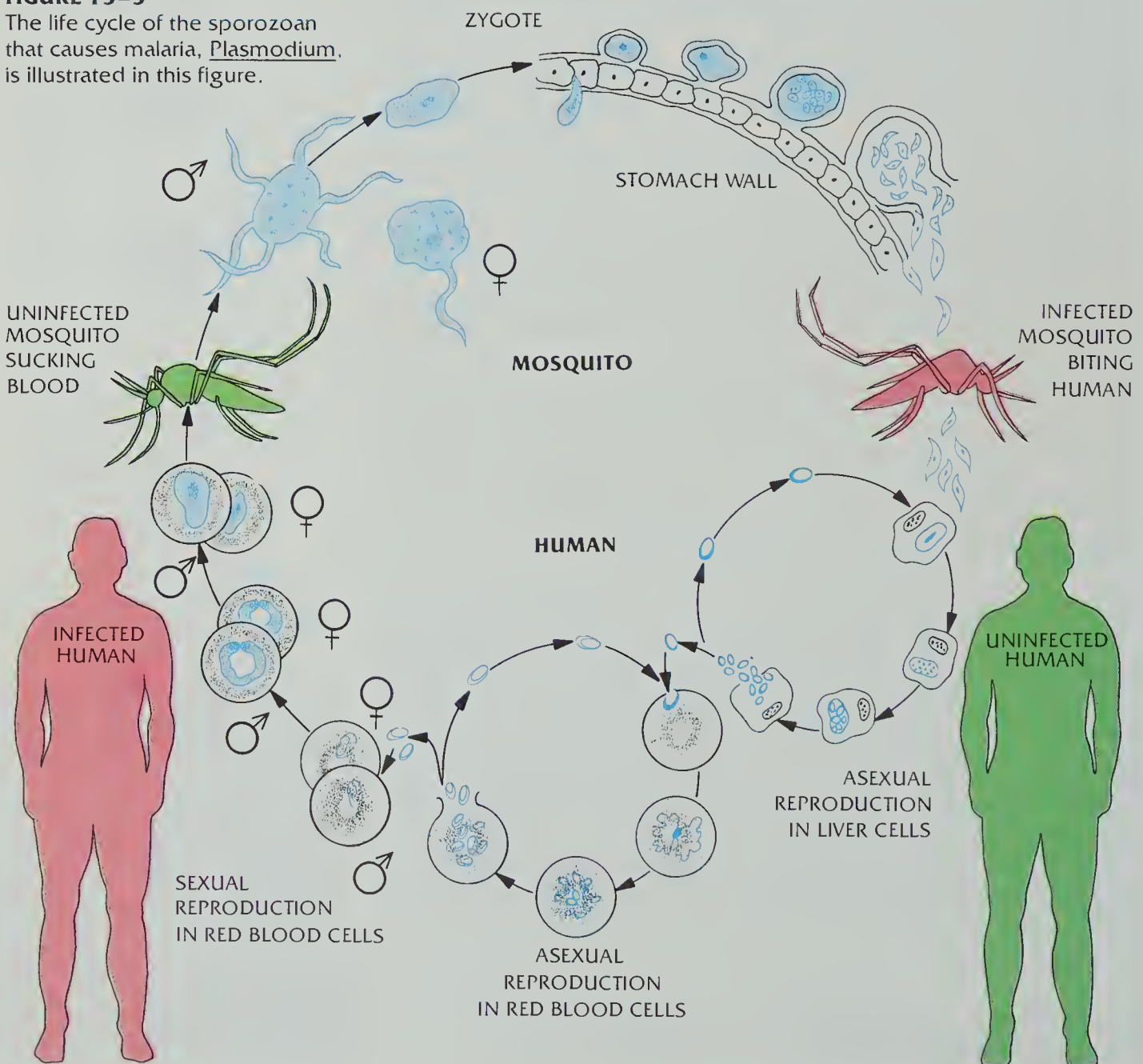
The phylum Sporozoa consists entirely of parasites. They have complex life cycles, sometimes with two hosts, and they reproduce both sexually and asexually.

Although the sporozoa have complex life cycles, their structure is rather simple. They have fewer organelles or specialized structures than do the other protozoa. The sporozoa get their name from the fact that they all form spores.

Sporozoa are the cause of malaria and other diseases in humans. Malaria is probably the most widespread disease in the world. It affects millions of people in the tropical and subtropical regions of the world. *Plasmodium* (plaz mō'dē əm) is the genus of the sporozoan that causes this disease. Like many other sporozoa, *Plasmodium* requires two hosts to complete its life cycle. In this case the two hosts are humans and mosquitoes. *Plasmodium* reproduces sexually in the mosquito and asexually in humans.

FIGURE 15-5

The life cycle of the sporozoan that causes malaria, *Plasmodium*, is illustrated in this figure.



When an infected mosquito bites a human, the parasite is injected into the human's bloodstream. *Plasmodium* makes its way to the person's liver and begins to multiply. Spores are formed in the liver and enter the bloodstream again. Each spore enters a red blood cell and multiplies again. So many new spores are formed that the red blood cell bursts open. These spores each find yet another red blood cell and start the process all over again.

In some infections this cycle takes 48 h. Every 48 h the growth of spores causes red blood cells to burst. The release of spores and poisons from the red blood cells causes violent chills and high fever. The reappearance of these symptoms every 2 d is a sure sign of malaria.

When a mosquito bites an infected person, it sucks up spores along with the blood. The parasite grows in the mosquito's stomach and reproduces sexually. The offspring work their way to glands in the mosquito's mouth. The next time this mosquito bites a human, the parasites will be injected. The cycle of infection begins again.

CHECK YOUR FACTS

1. What kind of organisms are found in the kingdom Protista?
2. What are the two major groups of protists?
3. What structures do amoebas use for locomotion and to capture food?
4. Name two groups of protozoa that are related to the amoebas.
5. Where are most flagellates found?
6. Which phylum of protozoa is thought to be the oldest?

SCIENCE BACKGROUND

Eimeria is a genus of sporozoa that is related to *Plasmodium*. Members of this genus are enteric parasites of many vertebrates. *Eimeria* is sometimes a problem in the poultry industry.

ANSWERS TO CHECK YOUR FACTS

1. Unicellular and colonial eucaryotes.
2. Protozoa and protophytes.
3. Pseudopodia.
4. *Radiolaria* and *Foraminifera*.
5. Within other organisms.
6. Phylum Mastigophora.

The Plantlike Protists

15–6 Phylum Chrysophyta The plantlike protists are found in waters throughout the world. A number of species live in ponds, rivers, and lakes, but most live in the oceans. These organisms are always found near the surface of the water where they can capture the sunlight. They form an extremely important part of the **plankton** (plangk'tən). The term *plankton* includes all the tiny organisms that float near the surface of the water. The plantlike protists in the plankton perform most of the photosynthesis that occurs in the world. If this surprises you, remember that three fourths of the earth's surface is covered by water.

Phylum Chrysophyta (krī sof'əd ə), which includes the golden algae and the **diatoms** (dī'ə toms), is the larg-

MAIN IDEA

The phylum Chrysophyta includes the golden algae and the diatoms. These and the other protophytes are planktonic.

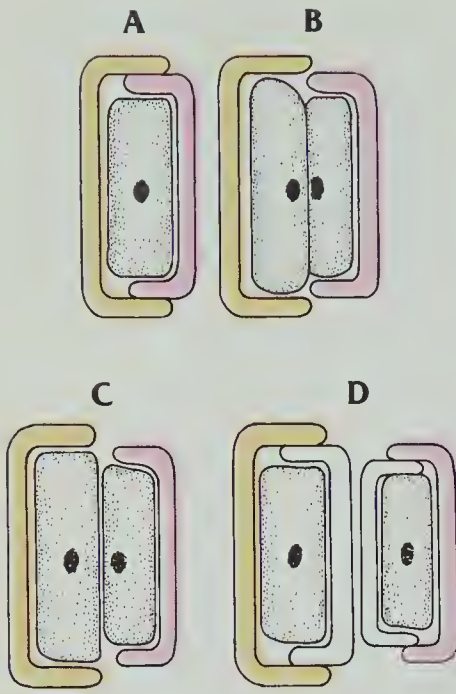


FIGURE 15-6

When a diatom undergoes asexual reproduction, each daughter cell receives half of the silica cell wall and makes the other half.

SCIENCE BACKGROUND

When diatoms divide, the daughter cells always form a new half-wall *inside* the original half-wall. This causes a given lineage of diatoms to become smaller and smaller in each generation. When a critical small size is reached, the wall is discarded and meiosis ensues with the production of gametes. New individuals produced by sexual reproduction are at the maximum size for the species.

est group of plantlike protists. A mixture of yellow and brown pigments, along with chlorophyll, gives these organisms their golden-brown color. The diatoms differ from the other golden algae by making beautiful, glassy cell walls of silica. There are about 10 000 species of diatoms and they are an important source of food for the animal life of the sea.

The cell walls of diatoms have fascinating patterns of spots and grooves on them. Each species of diatoms makes a wall with a different pattern. These walls are made of two overlapping halves. When a diatom divides, each daughter cell gets one half of the wall. Each daughter cell then makes a new half-wall to match the old one. Despite having to duplicate their beautiful walls, diatoms reproduce quite rapidly. They are among the most numerous organisms on earth. Only the bacteria occur in larger numbers.

Because the cell walls of diatoms are made of silica, they do not decay when the diatoms die. These glassy walls fall to the bottom of the ocean year after year. In some places they form deposits that may be over a hundred metres thick. These deposits are known as **diatomaceous** (dī ə tə mā'shəs) **earth**. Diatomaceous earth is used for polishing and is sometimes included in toothpaste. Layers of diatomaceous earth are sometimes raised above sea level by movements within the earth.



The cell walls of diatoms show a variety of shapes and patterns.

A very large deposit of diatomaceous earth is found in Lompoc, California. It is about 350 m thick and covers an area of 30 km². Each cubic centimetre of this material contains the remains of 6 million diatoms. Just think of the astronomical number of diatoms that must have grown and died to make this deposit!

15-7 Phylum Pyrrophyta Since ancient times, sailors have been mystified by seeing the ocean's waters glow at night. We know today that a group of protists is responsible for this. The ability of a living organism to produce light is described as **bioluminescence** (bī ō lū mē nes'əns). The light is produced by **dinoflagellates** (din ə flaj'ə lāts), a strange group of unicellular algae. These organisms are classed in the **phylum Pyrrophyta** (pī'rō fī tə). They contain chlorophyll and use it in photosynthesis. They also contain other pigments, and many of them appear in reddish colors. Almost all dinoflagellates live in salt water.

Dinoflagellates have two flagella, which lie in grooves on the cell wall. One of the flagella circles about the middle of the organism, while the other trails out behind. The trailing flagellum propels the organism, while the circular one seems to be used for steering.

The cell wall of dinoflagellates is made of cellulose, like that of true plants. Sometimes the wall is smooth and in one piece. In other dinoflagellates the cell wall is made of many separate pieces that are cemented together. This type of wall looks like armor plating.

At certain times dinoflagellates suddenly start to reproduce in tremendous numbers. This gives rise to the condition known as red tide. Biologists are not sure why this happens, but it happens every year somewhere along the Atlantic or Pacific coast. The dinoflagellates can reach concentrations of 60 000/mL of water. The reddish color of the organisms gives the name to the tide.

Some dinoflagellates release poisons into the water. The large number of these organisms present during a red tide produces enough poison to kill many fish. Mussels and clams can accumulate the poison without being killed. But people who eat contaminated shellfish during a red tide can become quite ill. A red tide on the coast of New England in the summer of 1972 caused many people to be hospitalized.

15-8 Phylum Euglenophyta Is it a plant or is it an animal? Better not to ask. *Euglena* is so unique that it and its close relatives are given a phylum of their own.

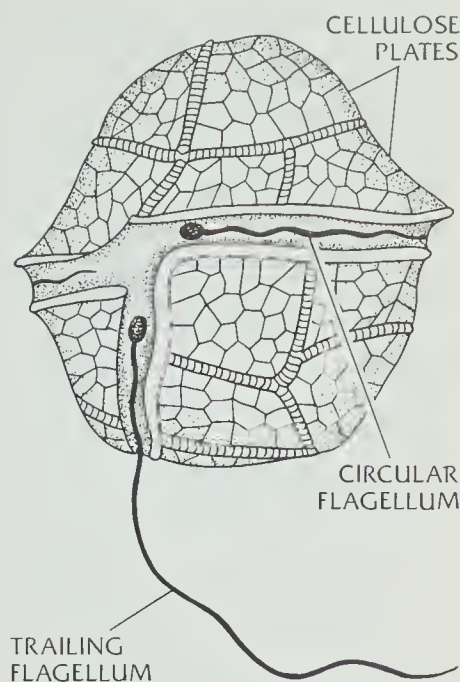


FIGURE 15-7

In dinoflagellates, the trailing flagellum is used for locomotion and the circular flagellum is used for steering.

SCIENCE TERMS

plankton
phylum Chrysophyta
diatoms
diatomaceous earth
bioluminescence
dinoflagellates
phylum Pyrrophyta
phylum Euglenophyta
eye spot

MAIN IDEA

The phylum Euglenophyta is a small group of photosynthetic flagellates that present a mixture of plantlike and animallike characteristics.

SCIENCE BACKGROUND

The classification of the euglenophytes is perennially debated. The chief alternative to the system used in this text is the inclusion of the euglenoids in the phylum Mastigophora. In that system, two subphyla are recognized: subphylum Zoomastigina, which includes the heterotrophic flagellates, and subphylum Phytomastigina, which includes the photosynthetic flagellates.

This is the **phylum Euglenophyta** (yü glē'nō fī tā). *Euglena* is a unicellular organism that blends the traits of both animals and plants. It has chloroplasts and nourishes itself, at least partly, by photosynthesis. But it also takes in solid food particles at times. *Euglena* is treated here as a plantlike protist because it is a protist with chloroplasts.

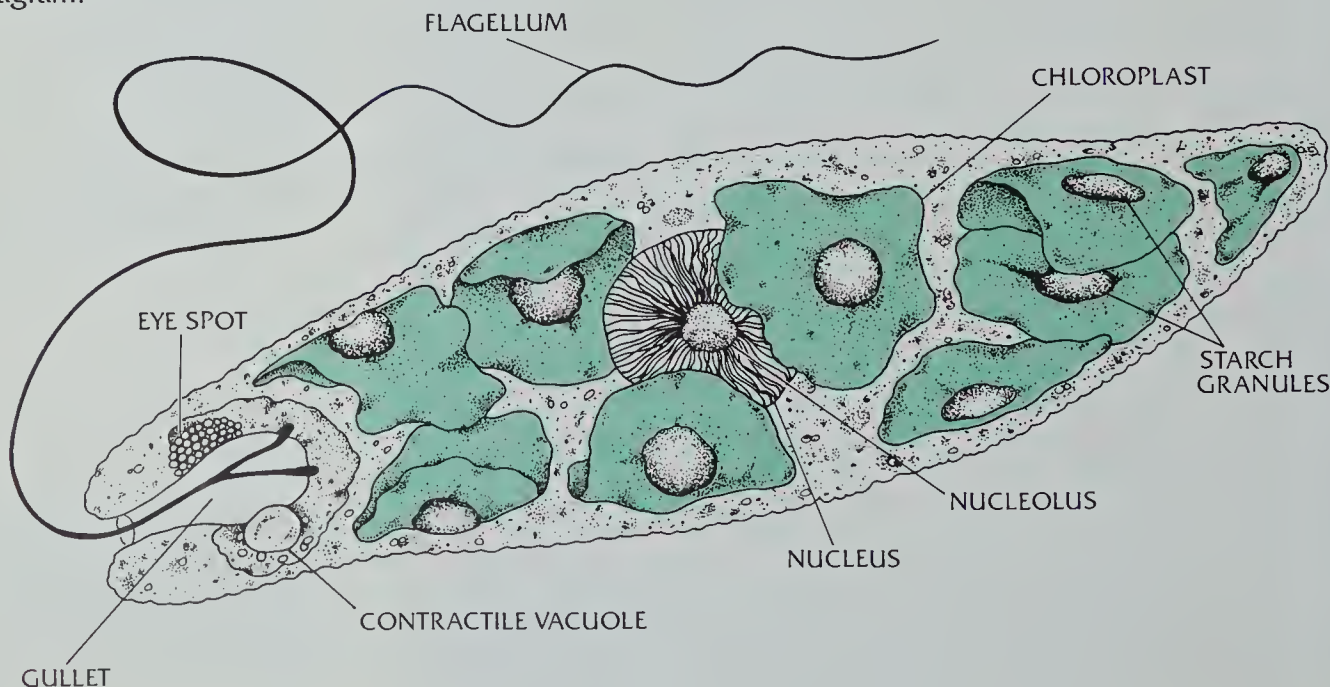
Euglena and its relatives live in ponds and damp soil. Like the protozoa, it forms a cyst when conditions are unfavorable. It has a pellicle instead of a cell wall to keep its shape. It stores food in the form of starch granules, the way many plants do. *Euglena* has a contractile vacuole very much like that of protozoa. It also has a gullet, but it is not clear whether the gullet is used to take in food particles. The contractile vacuole empties out through the gullet.

A flagellum projects from the front end of *Euglena* and curls back alongside the cell. *Euglena* moves by rotating the flagellum around its body. This action is somewhat like the spinning blade of a helicopter. The action of the flagellum pulls the cell forward rather than pushes it. *Euglena* has a pigment spot, or **eye spot**, which can detect light. Using its flagellum and its eye spot, *Euglena* moves about seeking bright areas in its environment.

When *Euglena* is in bright light it probably makes most of its food by photosynthesis. In darkness it nourishes itself largely by absorbing dissolved organic matter from the water. It is sometimes seen to absorb solid food particles in the area around the gullet. When kept in complete darkness in the laboratory, some *Euglena* dissolve their chloroplasts. Thereafter they live like protozoans, whether it is light or dark.

FIGURE 15-8

The structure of *Euglena*, a protist that can perform photosynthesis but also ingests food, is shown in this diagram.



CHECK YOUR FACTS

1. Which organisms perform most of the photosynthesis that occurs on earth?
2. Which organisms make cell walls of silica?
3. What group of plantlike protists make the ocean glow at night?
4. On which end of *Euglena* is the flagellum found?

SUMMARY

The kingdom Protista contains a wide variety of unicellular and colonial organisms. They are all eucaryotic. Protists are found as animallike forms called protozoa and as plantlike forms called protophytes. Protozoa have several ways of moving about. Amoebas, which are members of the phylum Sarcodina, move by means of pseudopodia. Members of the phylum Mastigophora use flagella for locomotion. The phylum Ciliophora contains the most complex protozoans. They use their cilia for locomotion. The phylum Sporozoa contains many parasitic protists that have no means of movement in their adult forms.

REVIEW QUESTIONS

1. What types of foods do protozoans eat?
2. Explain how a contractile vacuole works.
3. Two phyla of protozoa contain many parasites. Which two are they? Two phyla of protozoa are mostly free-living. Which two are they?
4. Give two examples of symbiosis between protozoa and higher animals.
5. Why are red tides dangerous?
6. How are the flagella of dinoflagellates arranged and how are they used?
7. What is amoeboid motion?
8. How are pseudopodia formed?
9. What is the difference between monerans and protists?

ANALYSIS AND APPLICATION

1. The ciliates are the most complex protozoa and are almost all free-living. The sporozoa are all parasites and they have the simplest structure of all protozoa. Is this a coincidence or is there a relationship between simple structure and parasitic life style?
2. Why is the conjugation of *Paramecium* considered to be sexual reproduction?

ANSWERS TO CHECK YOUR FACTS

1. The protophytes.
2. The diatoms.
3. The dinoflagellates.
4. On the front end.

ANSWERS TO REVIEW QUESTIONS

1. Bacteria, unicellular algae, and smaller protists.
2. Excess water enters the vacuole, the vacuole contracts, and the water is forced out.
3. Most are in the phyla Sporozoa and Mastigophora. Sarcodina and Ciliophora.
4. Grass-digesting protozoa in cows' stomachs and wood-digesting flagellates in termites.
5. Shellfish accumulate dinoflagellate toxin and may poison humans who eat them.
6. Circular flagella for steering and trailing flagella for propulsion.
7. Movement by forming one pseudopod after another.
8. By movement of the endoplasm that pushes the plasma membrane outward.
9. Monerans are procaryotes and protists are eucaryotes.

ANSWERS TO ANALYSIS AND APPLICATION

1. Simplified or degenerate structure is common among all types of parasites. This is generally a consequence of being nourished and shielded from the environment by the host. Structures used for pursuing or making food and for protection are dispensed with.
2. The crossing-over and fusion of micronuclei achieves the same end as the fusion of gametes to form a zygote.

Investigation 30 from *Laboratory Investigations in Biology* can be done with this chapter.

OBJECTIVES

- To list the characteristics of thallophytes
- To recognize differentiation into simple organs in the brown algae
- To name the commercial uses of kelps
- To introduce the concept of

16 *Algae and*



- adaptation
- To name the uses of red algae
- To understand why the green algae are thought to be closely related to higher plants
- To discuss the variety of form in green algae
- To explain the reproductive

- cycles in the green algae
- To understand the classification of fungi
- To explain the role of fungi as decomposers
- To understand the life cycle and growth habits of *Rhizopus*
- To describe ascus formation

- To identify some common ascomycetes
- To understand that a mushroom is the reproductive organ of a saprophytic underground mycelium
- To discuss reproduction in basidiomycetes
- To explain the characteristics of cellular and acellular slime molds
- To describe the nature of lichens and their distribution in nature
- To understand the importance of mycorrhizae in the nutrition of woody plants

Fungi

The Higher Algae

16-1 The brown algae The term *algae* is a general name for many varieties of photosynthetic organisms that live in water. We have already discussed the blue-green algae and the golden algae. The blue-green algae are prokaryotic. The golden algae and others are protists. There are three additional groups of algae that are classified as true plants. They are included in the **kingdom Plantae** and are called the higher algae.

The higher algae are included in the plant kingdom because most of them are multicellular. There is some specialization of cells in these algae. For example, some cells form air bladders to help the algae float. Other cells form supporting structures in algae that attach to the ocean bottom. Some cells specialize in photosynthesis. In many of the higher algae, only certain cells can participate in sexual reproduction. These differences between cells in higher algae represent a division of labor. It is this division of labor that makes the difference between a colony and a multicellular organism.

Although the higher algae are thought of as plants, they are different from the land plants that we see around us. They are much simpler and do not have roots, stems, or leaves. A plant body without roots, stems, or leaves is called a **thallus** (thal'əs). Plants that grow in the form of a thallus are known as **thallophytes** (thal'ə fītz).

Thallophytes also differ from land plants in that they have no vascular tissue. **Vascular** (vas'kyə lər) **tissue** is a system of tubes found in land plants. It is used for con-

MAIN IDEA

The red, the green, and the brown algae are placed in the plant kingdom because they have the characteristics of multicellular organisms. The brown algae are the most advanced of these groups.

SCIENCE BACKGROUND

In some systems of classification, all algae are classed as protists. In other systems, all algae are classed as plants. The system used here, dividing the algae between the protist and the plant kingdoms is predicated on the definition of a plant as a multicellular autotroph.

ducting materials from place to place like a plumbing system. Because thallophytes have no vascular tissue, they are never more than a few cells thick. Some grow to lengths as great as 60 m, but even these are very slender. They depend on diffusion to get materials from place to place. If the bodies of thallophytes were very thick, the cells in the center would be unable to get nutrients from the surrounding water.

In the plant kingdom the word **division** is used in place of *phylum*. There are three divisions of algae included in the plant kingdom. They are named for their colors, but they also differ in many other characteristics:

Division Phaeophyta (fī əf'ə tə)—the brown algae

Division Rhodophyta (rō də'fə tə)—the red algae

Division Chlorophyta (klô rə'fə tə)—the green algae

Like plants, the red and the brown algae contain chlorophylls. The green algae also contain other pigments.

The brown algae are almost entirely a saltwater group. They are most likely to be found in rocky coastal areas of the cooler oceans. Brown algae reach their greatest size on the coast of the Pacific Northwest. Some species of brown algae prefer to grow near the water's edge where they are exposed to air at low tide. Others are found in deeper water, growing at depths of up to 30 m. They attach themselves to rocks to keep from being thrown about by wave action. These algae range from brown to olive green in color. The brown pigment, **fucoxanthin** (fyü kō zan'thēn), mixes with chlorophyll to produce the various colors found in these algae.

Fucus grows at the water's edge. This alga is known as rockweed and is about 0.5 m in length. It anchors itself to rocks by means of a **holdfast**. This is the enlarged lower end of the thallus. The holdfast may have projections that look like spreading roots. They are not really roots, but they make a gluelike substance that holds tight to the rocks. The **stipe**, which resembles a stem, grows upward from the holdfast.

The stipe supports several flat **blades**. The cells of the blades carry on photosynthesis. **Air bladders** within the blades keep the plant upright in the water. This allows *Fucus* to catch as much light as possible. Without the bladders the blades would fall on each other. They would not get as much light.

At the upper ends of the blades are structures called **receptacles** (ri sep'tə kels). These are the reproductive organs of *Fucus*. Within the receptacles, eggs and sperm are produced and released into the water. The sperm have two flagella and swim through the water until they find an egg.

SCIENCE BACKGROUND

Fucoxanthin is one of a large family of pigments called xanthophylls. Xanthophylls and the related carotenes occur in shades of red, orange, yellow, and brown. One or another form of these pigments occurs in almost all plants and in some animals, too.

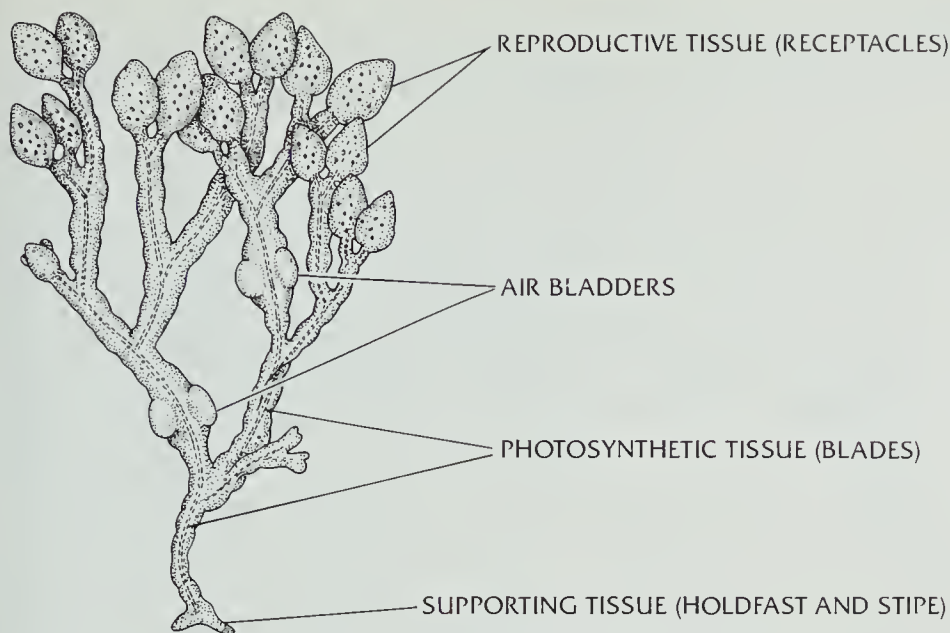


FIGURE 16-1

Fucus, illustrated above, is a complex alga that resembles a higher plant. However, it has no vascular tissue.

After an egg is fertilized by a sperm, it settles to the bottom. The growth of a new thallus begins.

The family of brown algae known as kelps are the largest and most advanced of all algae. Kelps grow in water from 3 to 30 m deep. *Laminaria* is a common kelp of both the Atlantic and Pacific coasts. Its blades can grow as long as 5 m. It grows so densely in some areas that it looks like an underwater forest. Two related kelps, *Nereocystis* and *Macrocystis*, are found on the Pacific coast. *Macrocystis* is called the giant kelp because it sometimes grows to 60 m in length. These two algae are a rich source of food for the animal life of the North Pacific Ocean.

Nereocystis resembles *Fucus*. It consists of a holdfast, a long stipe, a single large air bladder, and many blades. Internally *Nereocystis* is quite different from *Fucus*. A cross section of the stipe shows that it is made of several types of cells. On the outer edge are small, closely packed cells that form an **epidermis** (ep ə dër'mis), or skin. Under these are larger cells whose main function is photosynthesis. In the center of the stipe there are columns of thick-walled cells. These function as a primitive vascular tissue. The kelps are the only algae to have this type of tissue. Perhaps this is what enables them to grow so large. This tissue is much simpler than the vascular tissue of land plants. It brings the products of photosynthesis from the blades to the holdfast. The holdfast may not get enough light to make its own food.

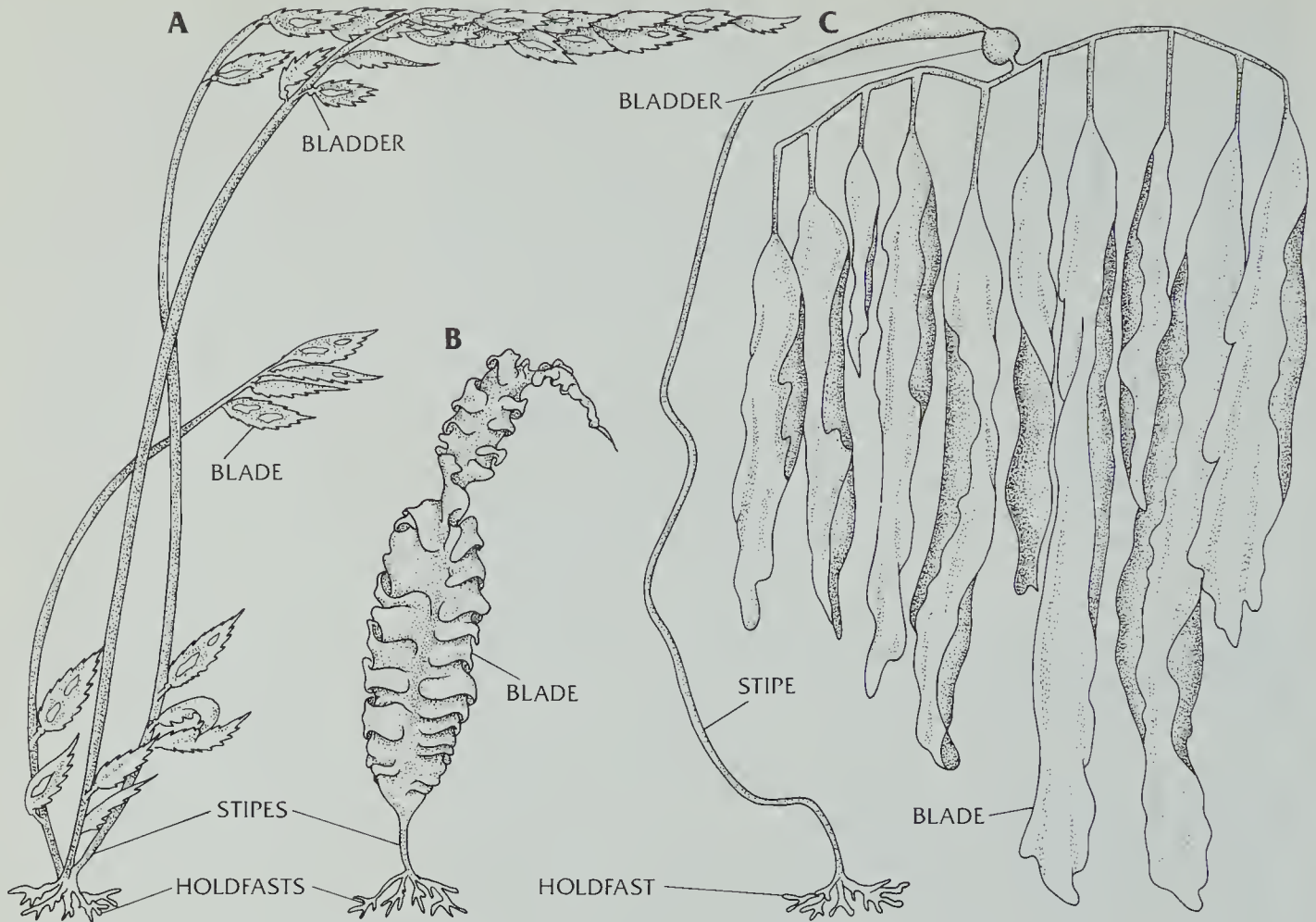


FIGURE 16-2

Examples of brown algae known as kelps: **A.** *Macrocystis*, the giant kelp; **B.** *Laminaria*; **C.** *Nereocystis*.

Although the majority of brown algae are coastal dwellers, one group prefers the open sea. The members of the genus *Sargassum* take their name from the Sargasso Sea. This is a vast area of water in the mid-Atlantic bounded by Bermuda, the Bahamas, and the Azores. *Sargassum* grows very thickly in these waters. It forms large floating masses that may be hundreds of metres across.

The brown algae, especially the kelps, are commercially valuable. They concentrate iron, iodine, and other minerals from the sea water. For this reason, brown algae are sometimes used as fertilizer and as cattle feed. In Japan they are harvested for human consumption.

Brown algae make cell walls of cellulose and a second substance called algin. This is a gummy material that helps to hold the cells of the algae together. It also serves to attach the holdfast to the rocks. Algin holds water and may protect brown algae from drying when they are exposed to air at low tide.

In California, kelps are harvested commercially for their algin content. This product has many uses in the food and cosmetics industries. Algin is widely used in the manufac-

ture of ice cream. It prevents the formation of ice crystals and gives ice cream a smooth, creamy texture. It is also used to improve the texture of toothpastes and cosmetics.

16-2 The red algae Like the brown algae, the red algae are found almost entirely in salt water. But the red algae prefer warmer and deeper waters. A few species grow in the North Atlantic, but many more grow in tropical waters. Red algae have been found growing as deep as 170 m in clear water. This is about as deep as any plant can grow in the ocean. Below this level there is not enough light for photosynthesis.

The red algae get their color from the pigment **phycoerythrin** (fī kō ə rith'rin). This pigment is very effective in absorbing blue light and is an advantage to plants that live in deep water. The light that penetrates deep into the ocean is mostly blue. The phycoerythrin of red algae can absorb this light. The energy from the absorbed light is passed to chlorophyll and is used in photosynthesis. Chlorophyll by itself does not absorb blue light very well. The partnership between phycoerythrin and chlorophyll makes photosynthesis possible in deep water.

One of the few red algae found along the Atlantic seacoast is *Chondrus crispus*, or Irish moss. It grows on rocks

MAIN IDEA

The red algae are adapted for growth in deep water and are most abundant in tropical waters.

Red algae called coralline algae deposit limestone in their walls. They often grow associated with coral animals.



SCIENCE BACKGROUND

Algin, carrageenin, and agar are all carbohydrates, but they differ considerably in their structure. Algin is a polymer of sugar acids. Agar is a polymer of sulfated sugars. Carrageenin contains galactose and mannose sugars.



FIGURE 16-3

Although many green algae are unicellular or colonial, many have complex, multicellular plant bodies.

MAIN IDEA

The green algae are diverse in form, but they are united in sharing a biochemistry very similar to that of land plants.

and is shaped like a ragged lettuce leaf. *Chondrus* can be found growing at many levels. In sunny, shallow, tidal pools it may take on a bright green color. In fairly deep water it is a rusty brown. At greater depths, it becomes bright red. The increased amount of red pigment is necessary for photosynthesis in deep water. This relationship between color and depth is a fine example of how algae adapt themselves to their surroundings.

Irish moss and other similar red algae are used as food in many parts of the world. In Japan they are even cultivated on underwater bamboo racks in shallow bays. Two gelatinlike substances are extracted from red algae. One substance is carrageenin, derived from Irish moss; it is used as a thickener in puddings, salad dressings, and other foods. The second is agar, which is extracted from a red alga found in the Indian Ocean. Agar is the base for many culture media that are used for growing bacteria and molds in the laboratory.

Some tropical species of red algae deposit calcium carbonate (limestone) in their walls. These are called **coralline** (kôr'ə lin) **algae** because they often grow together with coral animals. These two types of organisms both contribute to the formation of coral reefs. Because the walls of coralline algae are of limestone, they are readily preserved. Fossils of coralline red algae have been found in rocks that are 500 million years old.

16-3 The green algae The largest of the three divisions of the higher algae are the green algae. There are freshwater and saltwater forms. The green algae include unicellular flagellated forms, colonies, and filaments. Also included are more complex types with a holdfast-and-blade construction like the brown and the red algae. Why are such different forms placed in the same division? Why aren't the unicellular green algae placed with the protists?

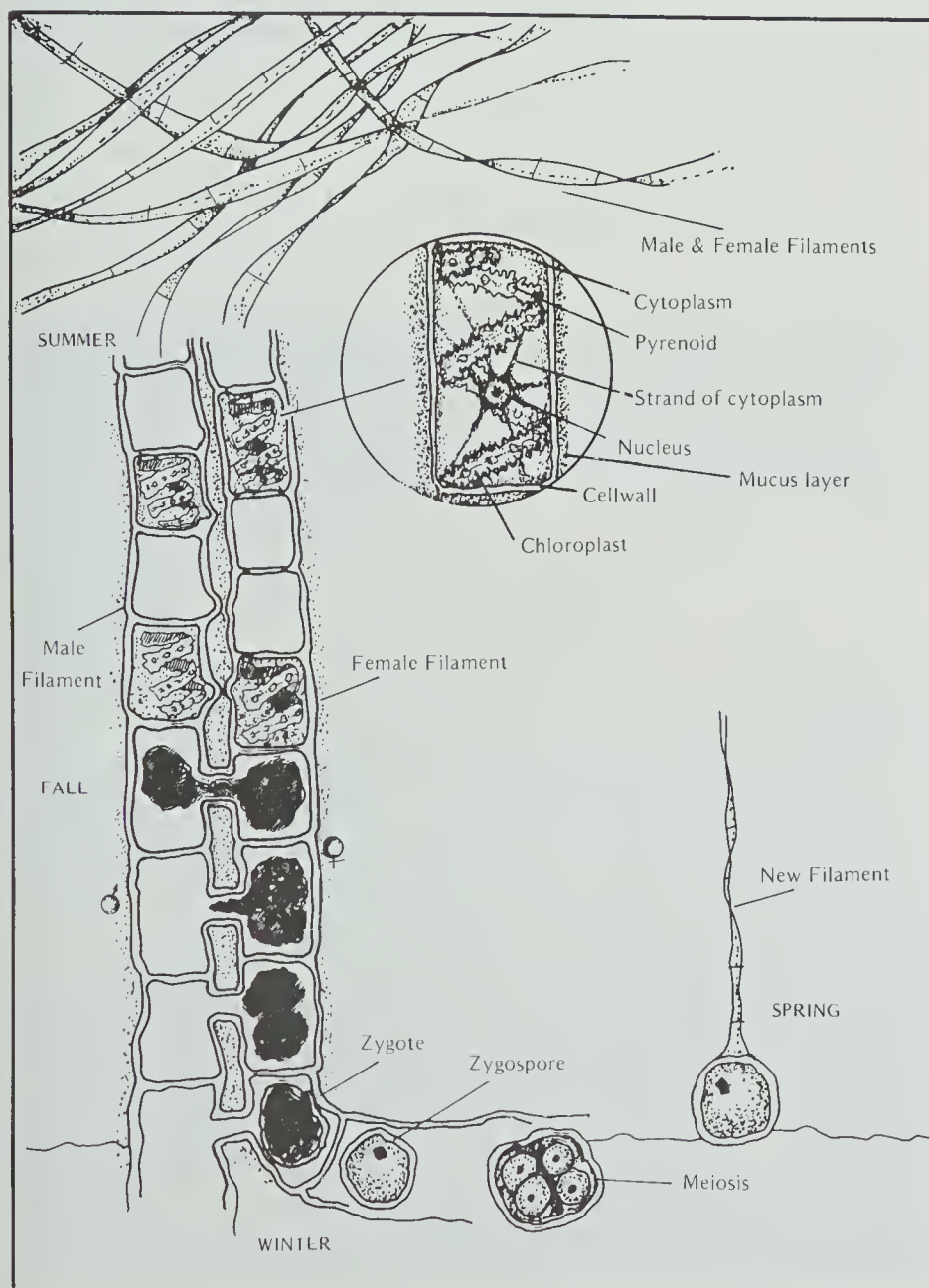
The answers to these questions lie in the chemistry of the green algae. The chloroplasts of plants contain several different types of chlorophylls. All the forms of green algae contain exactly the same chlorophylls as land plants. Other algae have different chlorophylls. The cell walls of green algae and of land plants contain the same mixture of chemicals. Land plants and green algae make the same types of starch as a means of food storage. The various types of green algae are closely related to each other. They, in turn, are more closely related to land plants than are the other groups of algae.

The green algae are represented at the unicellular level by *Chlamydomonas*. This organism resembles *Euglena*. It

has flagella, contractile vacuoles, an eyespot, and a chloroplast. But it does not have a gullet. It depends on photosynthesis for its food. *Chlamydomonas* also has a cell wall, which *Euglena* does not have.

Chlorella is another unicellular green alga. This has spherical cells of very simple structure. A large chloroplast and a nucleus are the only obvious features. It is very easy to grow in the laboratory and has been the subject of much research. Much of what we know about the details of photosynthesis has been learned from *Chlorella* and the knowledge is applicable to higher plants.

FIGURE 16-4 The sexual reproductive cycle of *Spirogyra*, a green alga, is illustrated below.



SCIENCE TERMS

kingdom Plantae
thallus
thallophytes
vascular tissue
division Phaeophyta
division Rhodophyta
division Chlorophyta
fucoxanthin
holdfast
stipe
blades
air bladders
receptacles
epidermis
phycoerythrin
coralline algae
vegetative
sporangium

SCIENCE BACKGROUND

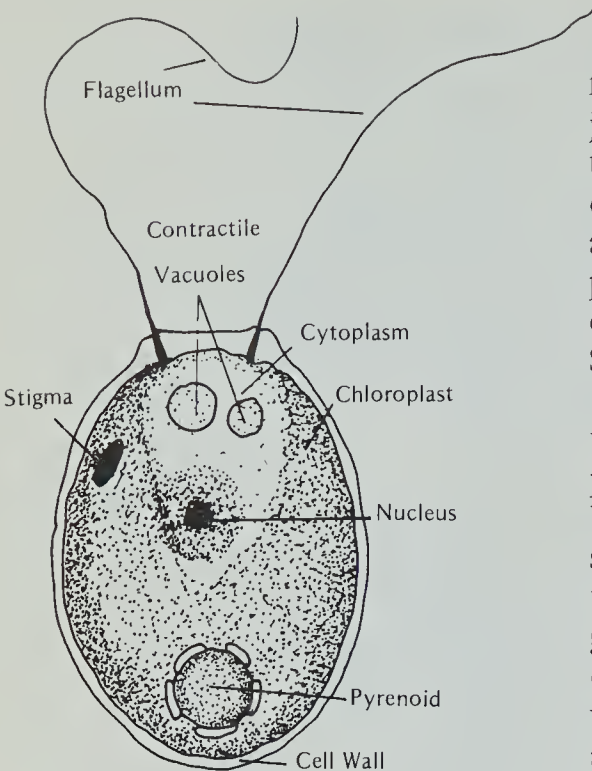
There are six varieties of chlorophyll found among algae and plants. These are designated *a*, *b*, *c*₁, *c*₂, *d*, and *e*. Green algae and land plants both contain chlorophylls *a* and *b*. No other group of algae contains chlorophyll *b*.

SCIENCE BACKGROUND

The cell walls of most plant tissues consist of cellulose and pectins. These same materials are found in green algal cell walls. Other algal groups vary in their cell wall composition.

SCIENCE BACKGROUND

Chlamydomonas is sometimes classified as a phytoflagellate protist. The presence of a cellulose-pectin cell wall and chlorophylls *a* and *b* recommends its inclusion with the green algae. *Volvox*, a colonial phytoflagellate, can be included with the green algae for the same reason.



Chlamydomonas: Parts of Chlamydomonas as distinguishable under the light microscope.

Many of the green algae of fresh water grow as colonial filaments. In these hair-like strands many identical cells are joined end-to-end. The filaments of *Spirogyra* can be found trailing from the rocks in a pond or stream. The cells in each strand are elongated and show little or no difference among each other. They are vegetative cells, involved in photosynthesis rather than reproduction. Typical of each cell is a spiral-shaped chloroplast band on which the name *Spirogyra* is based.

During the growing season, *Spirogyra* reproduces asexually. The method is called **fragmentation**. At certain places that are probably predetermined, the filaments break into several pieces, each developing into a new strand as new cells form by fission. As the growing conditions become less favourable near the end of the annual growing season, a form of sexual reproduction, called **conjugation**, takes place. At this time it becomes obvious that the single filaments that looked so much alike are in fact haploid female and male organisms. Two algal filaments become aligned and held in place by mucus. A male cell grows a projection. As this projection touches a female cell, a similar projection grows from it. When both projections touch, the separating cell walls dissolve and a conjugation tube is formed. The male cell contracts and slowly moves through the conjugation tube towards the female cell. This cell contracts, allowing the male to fuse with it, thus forming a diploid zygote. This is the only diploid cell in the life-cycle of *Spirogyra*. The zygote develops into a thick-walled **zygospore** which overwinters in a dormant state. In spring, meiosis takes place. Four nuclei are formed, of which only one survives. The resulting haploid spore germinates into a new filament and the cycle is repeated.

ANSWERS TO CHECK YOUR FACTS

1. Because they lack roots, stems, and leaves.
2. The coralline red algae.
3. The green algae.
4. In unicellular, filamentous, and complex forms.
5. Haploid.

CHECK YOUR FACTS

1. Why are the higher algae called thallophytes?
2. What type of algae contribute to the formation of coral reefs?
3. Which group of algae most resembles the land plants?
4. In what shapes do green algae occur?
5. Are the vegetative cells of *Spirogyra* haploid or diploid?

The Fungi

16-4 Classification of fungi The term **fungus** (pl. *fungi*) includes a broad variety of organisms. They are known by names such as yeasts, molds, mildews, rusts, mushrooms, and toadstools. You may already know that a yeast is quite different from a mushroom. This gives you an idea of how much variety there is among fungi. There are over 60 000 species of these organisms. They form a vital part of life on earth.

The classification of fungi has long been a problem in biology. The fungi have been classified as thallophyte plants. These organisms bear a surface resemblance to some of the algae. Fungi do not move about and many of them grow in the form of filaments. Some of the reproductive habits of fungi also resemble those of algae. One group of fungi produce spores in a sporangium, or spore case.

MAIN IDEA

Fungi have been classified traditionally as thallophyte plants. Heterotrophy and cell walls unlike those of plants lead some to classify fungi as a distinct kingdom.

SCIENCE BACKGROUND

Although fungi usually reproduce by spores, almost any fragment of a fungus is capable of growing into a new individual. There is one group within the Fungi Imperfecti that produce no reproductive structures whatsoever. These exist perpetually as hyphae.

Bracket fungi grow on both living and dead tree trunks and obtain nourishment from the tissues of the tree.



There are many reasons for believing that fungi are not closely related to plants. All fungi are heterotrophic. They contain no chloroplasts or chlorophyll. The cell walls of fungi are different from those of plants. The cell walls of fungi contain **chitin** (kī'tin). This is the material found in the shells of lobsters, crabs, and other animals. Chitin is not found in plants. Because of these differences many biologists consider the fungi to be a kingdom separate from the plants.

Fungi nourish themselves by absorbing organic matter that has been made by other organisms. Fungi are either saprophytes or parasites. The saprophytic fungi secrete enzymes into their surroundings to digest organic matter into simple molecules. The fungus then absorbs this digested food by diffusion. Parasitic fungi usually absorb nutrients directly from their host without the need to secrete enzymes. In either case, fungi always nourish themselves by absorption. They do not take in solid food particles like other heterotrophs. **Heterotrophs** (he'tēr ə trōfs) are organisms that depend on other living things for food instead of making their own.

Fungi play an important role in nature. Along with bacteria they bring about the decay of dead organisms. They return minerals and other nutrients to the soil. These nutrients are then available to be used again by plants. Without the activities of fungi the plants would soon remove all the nutrients from the soil. A few of the fungi cause diseases in animals and some cause diseases in plants. But the majority of fungi are saprophytes that live in the soil and water, serving a useful purpose.

The fungi are placed in the **division Eumycophyta** (yü mī kō fī'tə). There are four classes of fungi in this division. The four classes differ in their pattern of reproduction.

1. **Phycomycetes** (fī kō mī sīts') are fungi that resemble filamentous algae in their growth and reproduction.
2. **Ascomycetes** (as kə mī sīts') are fungi that produce spores in groups of four or eight. The spores form within a sac called an **ascus**.
3. **Basidiomycetes** (bə sid ē ō mī sīts') are fungi that produce spores in groups of four. These are carried on the outside of a structure called a **basidium** (bə sid'ē əm).
4. **Fungi Imperfecti** (im pər fik'tē) are fungi that are not known to reproduce sexually. This is an artificial grouping of fungi that do not fit into one of the other three classes.

All four of these classes of fungi have features in common. They grow as branching filaments called **hyphae**

(hī'fē). In some fungi these hyphae are made of individual cells that are attached end-to-end. In other fungi the hyphae are continuous tubes of cytoplasm with many nuclei. There is a wall on the outside of the tube. There are no cross walls to separate the nuclei from each other. The mass of hyphae that forms the body of a fungus is called a **mycelium** (mī sel'lē əm). Sometimes a mycelium consists of hyphae in a loose network. Such a fungus looks like a puff of cotton. In other fungi the mycelium is made of hyphae that are close together. A mushroom is an example of this type of mycelium in which the hyphae grow closely together forming a compact body.

Fungi do not need light. They generally grow where it is dark and damp. They grow most rapidly where it is warm, but they can also grow at near freezing temperatures. Molds sometimes appear on food that has been kept too long in the refrigerator. Fungi require oxygen. Only a few can grow in anaerobic conditions. Even these grow better when oxygen is available.

16-5 Phycomycetes Before the use of preservatives, any bread kept for more than a few days was sure to develop mold. The common bread mold, *Rhizopus stolonifer*, is a good example of a phycomycete fungus. As the hyphae of *Rhizopus* (rī'zə pəs) spread over a piece of bread they develop rootlike extensions. These are called **rhizoids** (rī'zoids) and they grow down into the bread. After a few days the hyphae start to form vertical branches, which stand up from the surface. These are the **sporangiophores** (spə ran'jē ə forz).

At the top of each sporangiophore, a round mass takes shape. This is a sporangium, or spore case. Inside the sporangium, thousands of tiny spores are formed. When the sporangium ripens, it bursts open and the spores are released. Each spore will grow into new hyphae if it lands in a suitable place.

Rhizopus reproduces sexually by conjugation. Conjugation occurs when two hyphae of different mating types are growing on the same piece of food. The hyphae of the two mating types form side branches that begin to approach each other. The nuclei in the hyphae are haploid. One nucleus moves into the tip of each branch, and a wall forms around it. This structure at the tip of each side branch is a gamete. When the two gametes contact each other, the wall between them dissolves. The nuclei of the two gametes join and form a zygote.

The zygote builds a very thick wall around itself and becomes a **zygospore** (zī'gə spôr). This may rest for several

MAIN IDEA

Phycomycetes reproduce sexually by conjugation and asexually by spores.

SCIENCE BACKGROUND

When phycomycetes engage in conjugation, pheromones, or chemical attractants, come into play. Hyphae of opposite mating types secrete pheromones into their surroundings. The hyphae find each other by following the concentration gradient of the pheromones.

SCIENCE BACKGROUND

Neurospora, a salmon-colored ascomycete mold, is sometimes found along with *Rhizopus* on old bread. This fungus has been the subject of extensive research in biochemical genetics. Much information about the control of protein synthesis has been obtained from these studies.

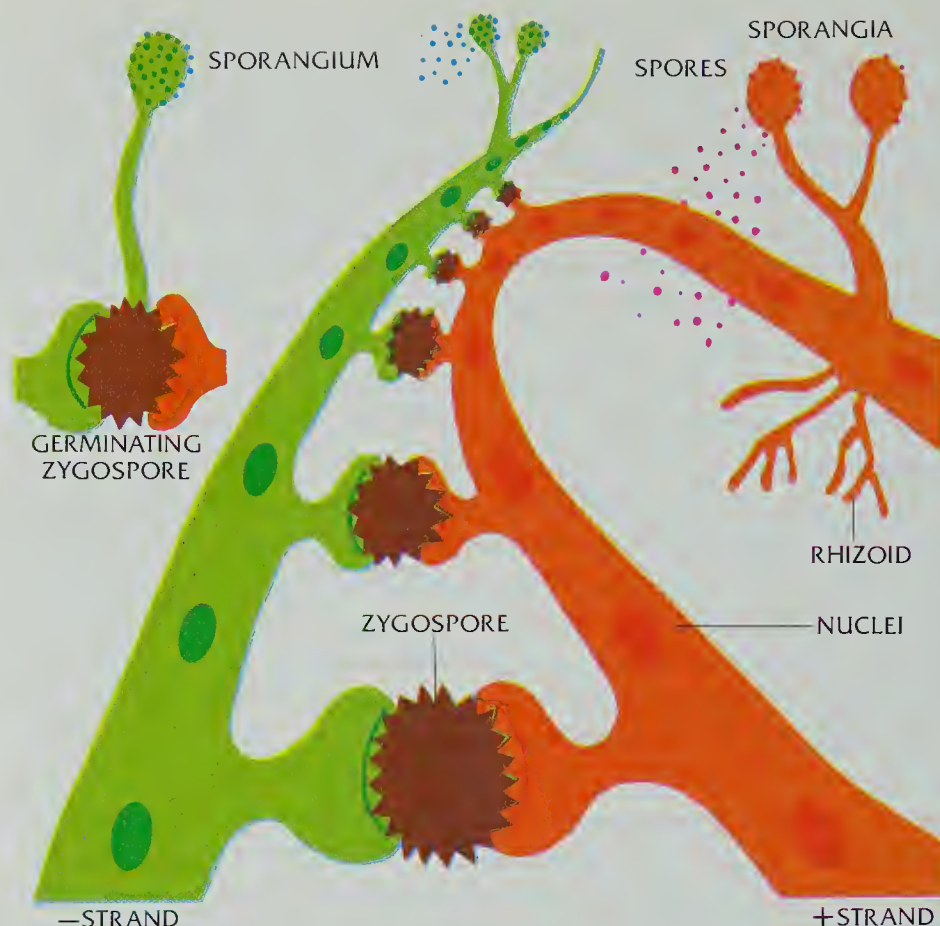


FIGURE 16-5 Sexual reproduction in *Rhizopus*, the common bread mold, is illustrated above.

months. When it starts to grow, meiosis takes place. The nuclei are haploid again. New hyphae begin to grow from the zygospore.

Other phycomycetes, besides *Rhizopus*, grow and reproduce in much the same manner. They grow on dead organic matter and in living plant tissues. Phycomycetes that are commonly known as blights and mildews cause a number of diseases in crop plants. Water molds cause the decay of dead plants and animals in lakes.

MAIN IDEA

Ascomycetes include the yeasts and green molds. These fungi produce spores in sacs called asci.

16-6 Ascomycetes Yeasts differ from other fungi in being unicellular. They do not form hyphae, but they do produce spore sacs in the same way that other ascomycete fungi do. Yeasts reproduce asexually by **budding**. In this process a mature yeast cell forms a small projection, or bud. The nucleus divides and one of the daughter nuclei moves into the bud. The bud then grows to full size. The new yeast cell may remain attached to the old one for a while. It will soon start to form its own bud to produce yet another new cell.

Yeasts also reproduce sexually and form spores. Two yeast cells unite and form a diploid nucleus. This undergoes meiosis to form four daughter nuclei. Each of these nuclei builds a thick wall around itself and becomes a spore. The cytoplasm of the original cell disappears. Its cell wall becomes a sac that contains the four spores. This sac is called an **ascus**. When the spores are ready, the ascus breaks, releasing them into the environment. Each spore grows into one new yeast cell if it lands in a warm, moist place.

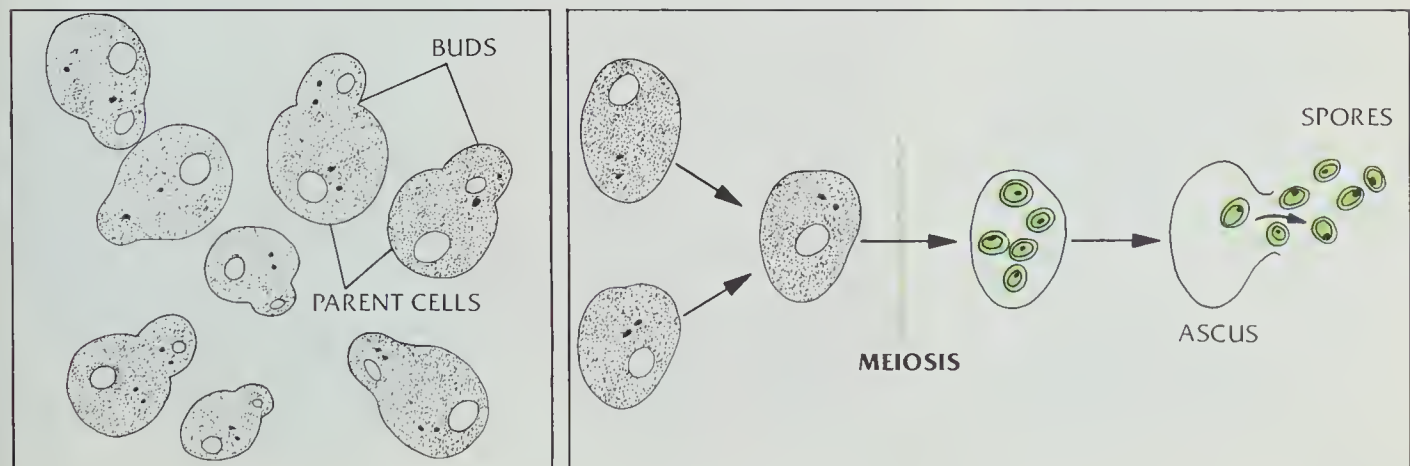
Yeasts of the genus *Saccharomyces* (sak ə rə mī'sez) are familiar to us as the yeasts used in baking and brewing. These yeasts are among the few fungi that can get along without oxygen. They ferment sugar to produce alcohol under anaerobic conditions. A few species of yeasts cause skin infections in humans.

Ascomycetes other than yeasts grow as hyphae, but they all produce spores in an ascus. The ascus is produced at the ends of some of the hyphae. Four or eight spores form within each ascus. Some ascomycetes also produce spores in another way. *Penicillium* (pen ə sil'ē əm) and *Aspergillus* (as pər jil'əs) produce spores in chains called **conidia** (kə nid'ē ə).

Penicillium and *Aspergillus* are very common molds. There are many species in each genus and they are found everywhere. Many of these molds are green or blue-green in color. These are the green molds often seen on spoiled fruit. *Penicillium* molds are used in production of cheese and in making antibiotics. Other ascomycetes of this family are known as powdery mildews. These cause infections in plants, usually in the leaves.

FIGURE 16-6

Asexual reproduction in yeasts (left) is called budding. Sexual reproduction involves the union of two yeast cells followed by meiosis.



MAIN IDEA

Basidiomycetes produce spores on a club-shaped structure called a basidium. Mushrooms, bracket fungi, and grain rusts are basidiomycetes.

SCIENCE BACKGROUND

The common edible mushroom, *Agaricus*, is very similar in appearance to *Amanita*, a highly toxic species. Students should be cautioned against eating wild mushrooms.

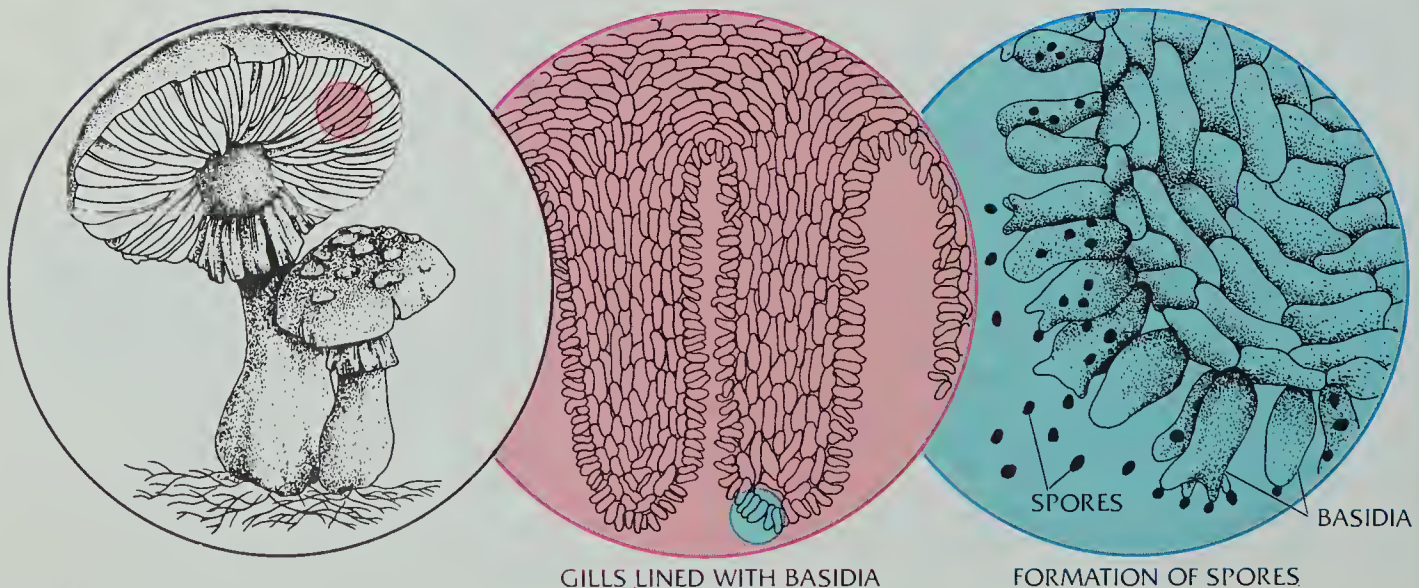
16–7 Basidiomycetes When you see a mushroom growing in the soil, you are only seeing part of a fungus. The umbrella-shaped mushroom is the reproductive part of the organism. It depends on a network of hyphae that spread through the soil in all directions. These underground hyphae gather food to support the aboveground mushroom. The underground hyphae obtain nourishment from decaying organic matter in the soil. The aboveground part of a mushroom is not really solid. It is made of many hyphae packed close together. These hyphae are continuations of the ones that grow underground.

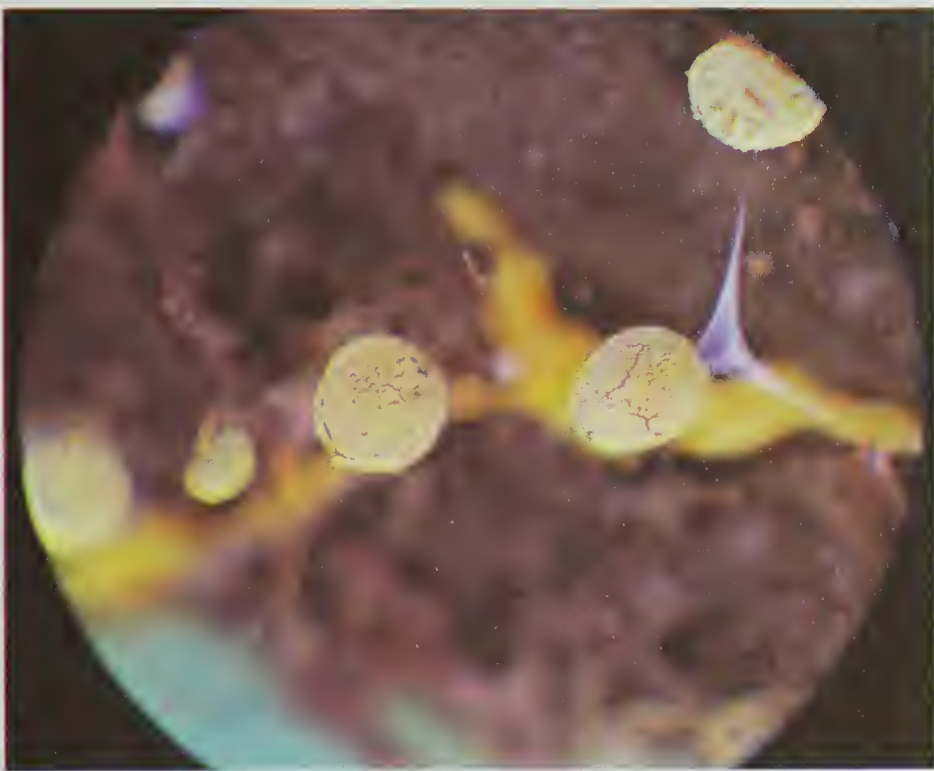
On the underside of a mushroom cap are many vertical partitions called **gills** (gills). The hyphae that form the gills end in enlargements called basidia. The basidia are the spore-forming structures in a mushroom. Each basidium usually forms four spores on its outer surface. These spores are carried away in the air to start the growth of new hyphae in another area.

Not all basidiomycetes look like mushrooms. These fungi occur in all shapes and sizes, but they all produce spores on basidia. Bracket fungi grow on both living and dead tree trunks. They look like small, rounded shelves on the sides of the tree. Other basidiomycetes form crusty growths on the surface of plant leaves. These are called rusts and are the cause of serious disease in many varieties of plants. One family of these rusts attacks wheat, oats, barley, and other grains. These fungi cause many millions of dollars worth of crop damage each year.

FIGURE 16–7

In mushrooms, spores are formed in basidia found on the underside of the cap. The spores are dispersed by the wind.





Sporangia, sometimes called fruiting bodies, can be seen at the tops of the stalks in this photograph of a slime mold.

16-8 *Amoeba or fungus?* It looks like a layer of slime on the floor of a damp forest. But it moves. It creeps slowly along, flowing over dead leaves and twigs, eating bacteria as it goes. What is it? It is a **slime mold**. This strange creature spends most of its life creeping along like a giant amoeba. But when it reproduces, it behaves like a fungus.

Slime molds exist in two varieties. One type, called **acellular** (a sel'yə lər) **slime molds**, contain many nuclei in a large amoeboid mass. There are no membranes separating the nuclei from one another. The other variety is the **cellular slime molds**. The body of this type is made up of many individual cells. Neither type of slime mold makes cell walls. These two kinds of organisms form the **division Myxomycophyta** (mik sō mī kō'fə tə).

Acellular slime molds are easily seen with the naked eye. They can cover areas of 20 to 30 cm² or more. They have an irregular shape that constantly changes. One edge of the slime mold is usually thicker than the rest. This is the forward edge where pseudopodia are formed to pull the slime mold along. Many twisting, branching strands of cytoplasm trail behind the leading edge. The cytoplasm in these strands streams forward to keep up with the rest of the slime mold.

MAIN IDEA

Slime molds are amoeboid organisms that form funguslike sporangia.

SCIENCE BACKGROUND

Movement in slime molds is mediated by the contractile protein myxomyosin. This is similar to the actin-myosin of muscle tissue.

SCIENCE BACKGROUND

The aggregation of myxamoebas to form a cellular slime mold is effected by cyclic-AMP (a derivative of ATP). Under adverse conditions the myxamoebas secrete this substance into their environment. Other myxamoebas are attracted by it and move toward its source.

SCIENCE TERMS

fungus
chitin
heterotrophs
division Eumycophyta
class Phycomycetes
class Ascomycetes
ascus
class Basidiomycetes
basidium
class Fungi Imperfecti
hyphae
mycelium
rhizoids
sporangiophores
zygospore
budding
conidia
gills
slime mold
acellular slime molds
cellular slime molds
division Myxomycophyta
myxamoebas
lichens
crustose lichens
foliose lichens
fruticose lichens
mycorrhiza



FIGURE 16-8

In a lichen the cells of the algae are interspersed among the hyphae of the fungus.

Acellular slime molds move along the forest floor, taking in bacteria and other small particles by phagocytosis. When the forest gets too dry, a slime mold will stop moving and will round up into a single mass. Stalks begin to grow upward from the surface of the slime mold. Sporangia form at the tops of these stalks. When the sporangia ripen, spores are released to be carried away on the wind. Spores that land in moist places release cells that have flagella. These cells act as gametes. When two gametes join, a new slime mold begins to grow.

The cellular slime molds behave quite differently. They spend most of their life cycle as single cells called **myxamoebas** (mik'sə mē bəs). When the surroundings become too dry, hundreds of thousands of these myxamoebas start swarming together. They unite to form a slime mold, which is about 1 mm in diameter. This soon changes to an almost wormlike shape and starts to move. After moving around for a while, the slime mold settles down in one place. A stalk grows upward and forms a sporangium. When the spores leave the sporangium, each releases a new myxamoeba. Myxamoebas can live indefinitely as single cells as long as good conditions continue.

16-9 Fungi and symbiosis Many fungi are involved in symbiosis with other organisms. **Lichens** (lī'kəns) are the best-known example of this type of relationship. A lichen is a partnership between an alga and a fungus. On the surface a lichen looks like a single plant. When viewed in cross section under a microscope, its true nature is revealed. The outer edges are made of the tightly woven hyphae of the fungus. In the center of the lichen the hyphae make a loose, airy network. Algal cells are usually found nested on one side of this network. This is the side where there is more light.

The fungus of a lichen is usually one of the ascomycetes. The algae are either of the green or blue-green varieties. There are hundreds of types of lichens. Each is a different pairing of alga and fungus. Lichens grow in three general shapes. The most common are the **crustose** (krus'tōs) **lichens**. These form flat, crusty-looking growths on rocks or hard-packed soil. **Foliose** (fō'lē ōs) **lichens** have the appearance of curly leaves. They are often found growing on the bark of trees in damp forests.

Fruticose (fru'tə kōs) **lichens** have a branching structure. They look like little bushes, 10 to 20 cm tall. *Cladonia*, a lichen of this type, covers vast areas of the Arctic region. Its common name is "reindeer moss," al-



A fruticose lichen has the appearance of a small bush. Some varieties of fruticose lichens are important as food for animals.

though it is not a moss at all. But it is an important food for caribou as well as for moose and other animals of the North.

Lichens grow in harsh environments where neither algae nor fungi could survive alone. Imagine a plant growing on bare rock in a sunny, dry location. Only lichens can do that. The network of hyphae in a lichen tends to trap and hold water. This makes a moist environment for the alga inside. The fungus secretes acids that slowly dissolve the rock. This provides minerals, which are needed by the alga. The alga, in turn, provides food for the fungus through its photosynthesis.

Lichens play an important part in nature. They gradually change the rocks they grow on into soil. Acids from the lichen cause the rock to crumble. Organic matter from the lichen and dust blown in by the wind mix with the crum-

MAIN IDEA (16-9)

Lichens are symbiotic associations between algae and fungi. Mycorrhizae are symbiotic associations between fungi and the roots of higher plants.

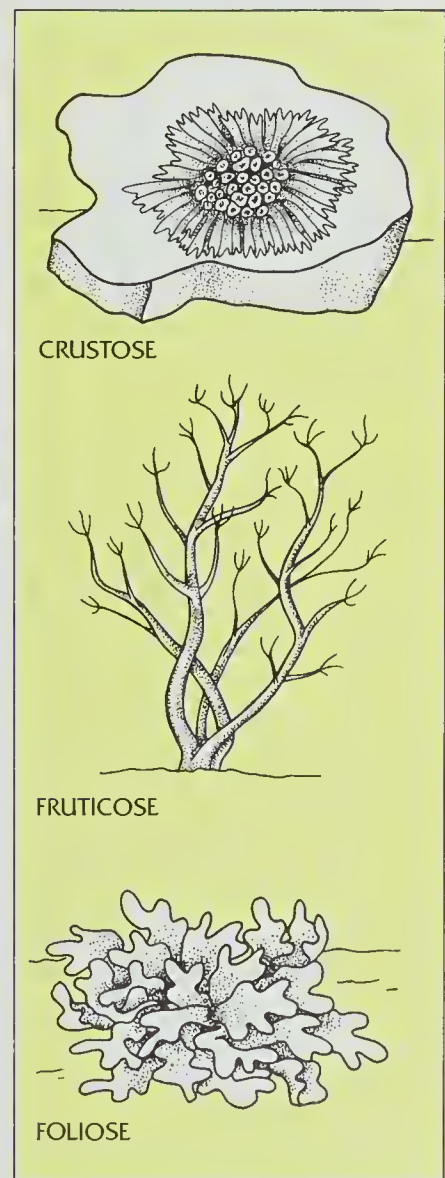


FIGURE 16-9

The three forms of lichens are illustrated in this figure.

ANSWERS TO CHECK YOUR FACTS

1. Crustose, foliose, and fruticose.
2. The cellular slime molds.
3. Ascomycetes.
4. A lichen.

SCIENCE BACKGROUND

Lichens are usually considered along with the fungi because the greater proportion of the lichen tissue consists of fungal hyphae. The general form of a lichen is determined by the species of fungus involved. Only the fungus in a lichen can reproduce sexually.

ANSWERS TO REVIEW QUESTIONS

1. The kelps have simple organs and primitive vascular tissue.
2. Red algae prefer warm water and grow deeper than brown algae.
3. Division Chlorophyta—

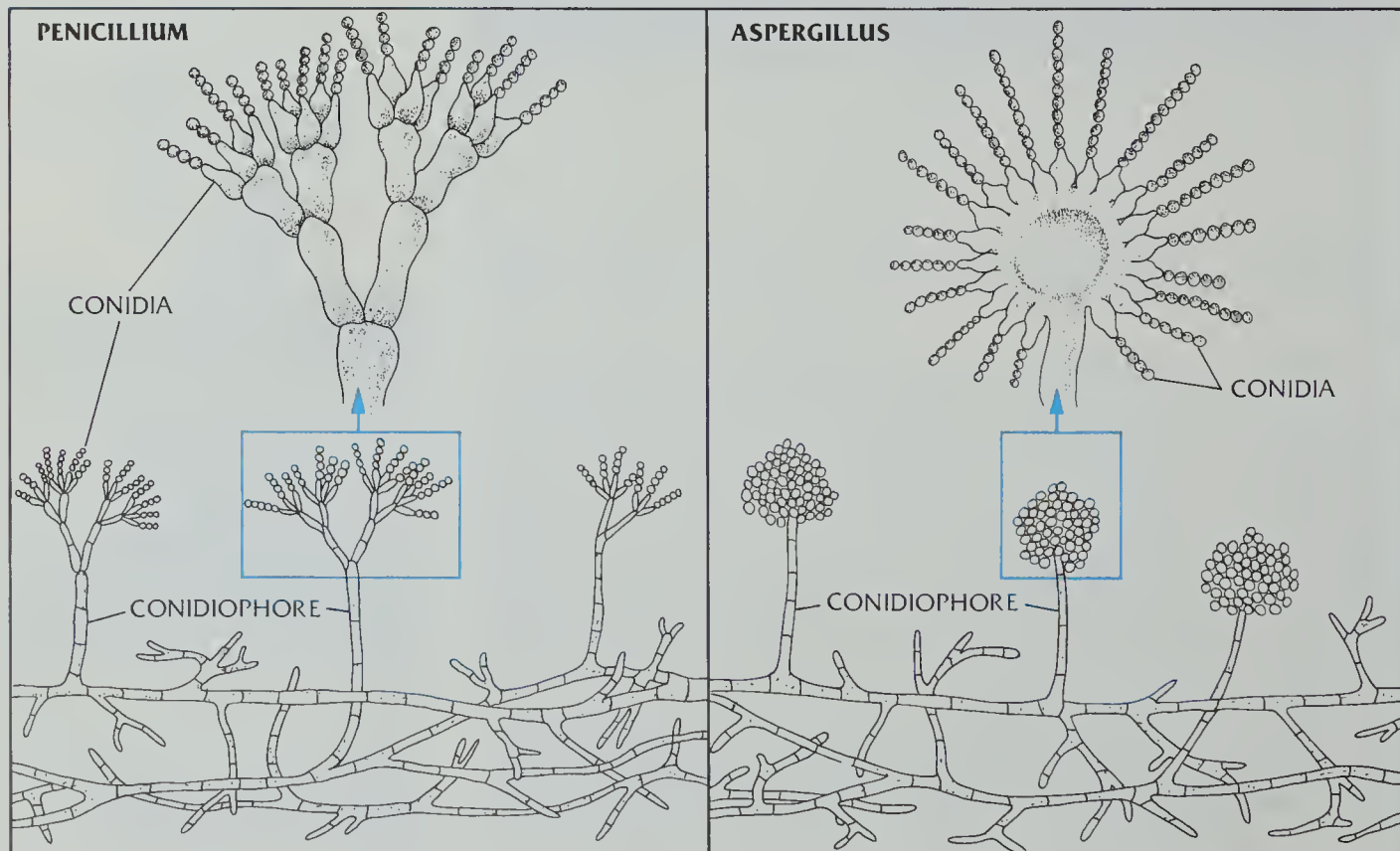
bled rock to form soil. This is a slow process, taking many years. But lichens live long, too. It is believed that some slow-growing lichens can live for hundreds of years.

Fungi participate in another type of symbiosis with the roots of trees and other woody plants. This type of association is called a **mycorrhiza** (mī kə rī'zə). This word literally means "fungus root." Some mycorrhizae form layers that coat the outside of plant roots. In other cases the hyphae of the fungus grow in between the cells of the root. Sometimes the hyphae even grow into the root cells.

The partnership in a mycorrhiza is much like that in a lichen. The fungus digests organic matter in the soil. It also produces acids that dissolve minerals in the soil. The minerals and other nutrients obtained by the fungus are made available to the plant root. The plant provides the fungus with the products of photosynthesis.

Mycorrhizae are necessary to many common trees. Pine trees forced to grow without mycorrhizae grow slowly and poorly. If the roots are then allowed to develop mycorrhizae, normal healthy growth will resume. Orchids also depend on mycorrhizae. No orchid has ever been found growing without them.

FIGURE 16-10 Both Penicillium and Aspergillus are ascomycetic molds that produce spores in conidia.



CHECK YOUR FACTS

1. What are the three general types of lichens?
2. Which type of slime mold spends most of its life as single amoeboid cells?
3. To what class of fungi do the green molds belong?
4. What type of organism is a “reindeer moss”?

SUMMARY

The red, the green, and the brown algae are classified as thallophytes in the kingdom Plantae. Many of these algae produce simple organs such as holdfasts and air bladders. Fungi are heterotrophic organisms that usually grow in the form of hyphae. Fungi resemble algae in their growth and reproduction. Fungal cells also have cell walls. But fungi also differ from plants in some important ways. They do not contain chlorophyll and do not perform photosynthesis. Parasitic fungi cause many diseases in plants and a few in animals. But the majority of fungi are useful saprophytes. A lichen consists of an alga and a fungus in a symbiotic relationship.

REVIEW QUESTIONS

1. What are some reasons for considering the kelps to be the most advanced group of algae?
2. Compare the habitats of red algae and brown algae.
3. Name the three divisions of higher algae and name the pigments found in each.
4. How does *Chlamydomonas* differ from *Euglena*?
5. Why are the higher algae classified as plants?
6. Explain what a lichen is.
7. How do fungi differ from plants?
8. Compare the formation of spores in the three major classes of fungi.
9. What happens to acellular slime molds when the environment becomes too dry?
10. What do slime molds have in common with fungi?

ANALYSIS AND APPLICATION

1. Explain why the color of red algae varies with the depth of the water in which they grow.
2. Explain the life cycle of *Spirogyra*.
3. How do most fungi nourish themselves? How is this system of nutrition beneficial to other organisms?
4. Explain the life cycle of a cellular slime mold.

chlorophyll; division
Phaeophyta—fucoxanthin and chlorophyll; division
Rhodophyta—phycoerythrin and chlorophyll.

4. *Chlamydomonas* is strictly autotrophic and has no gullet; it has a cell wall.

5. Because they are multicellular and have some specialization of cells.

6. A lichen is a symbiotic association between a green or blue-green alga and an ascomycete fungus.

7. Fungi lack chlorophyll and use chitin in their cell walls.

8. Phycomycetes produce large numbers of spores in sporangia; Ascomycetes produce spores in groups of four or eight within an ascus; Basidiomycetes produce spores in groups of four on a basidium.

9. They stop moving and form sporangia.

10. They form spores in sporangia.

ANSWERS TO ANALYSIS AND APPLICATION

1. Phycoerythrin is more efficient than chlorophyll in capturing light in deep water.

2. Asexual reproduction is by fragmentation. Sexual reproduction is by conjugation. Cells fuse to form a diploid zygote. After a rest period the zygote produces four spores by meiosis. All adult cells are haploid.

3. Most fungi are saprophytic. In decomposing organic debris, they liberate minerals and other simple nutrients that are then available for use by plants.

4. Myxamoebas aggregate to form a slime mold, which forms a sporangium, which releases spores, which germinate into new myxamoebas.

Investigation 31 from *Laboratory Investigations in Biology* can be done with this chapter.

OBJECTIVES

- To describe how a specific microbe is identified as the cause of a disease

- To distinguish between endemic, epidemic, and pandemic levels of infection
- To discuss the various modes of disease transmission
- To recognize the three most prevalent forms of venereal disease
- To understand the impor-

17

People versus



tance of early reportage and treatment in the control of venereal disease

- To describe exotoxins, endotoxins, and destructive enzymes
- To understand that proper sewage disposal and vector control inhibit the transmission of disease

- To explain that the skin and the mucous membranes form a structural defense against infection
- To understand that phagocytes destroy invading microbes
- To describe antigens and antibodies
- To state the role of lymphocytes in immunity

- To understand the nature of antibody action
- To explain that active immunity involves production of antibodies by lymphocytes
- To understand that passive immunity depends on antibodies from external sources
- To describe the methods of artificial immunization
- To learn the source of antibiotics
- To explain why microbes make antibiotics

Microbes

Microbes and Disease

17-1 The spread of disease Microbes are all around us in the air, soil, water, and even on our skin. Despite this, most of us manage to stay healthy most of the time. There are two sets of reasons for this. The first are the many natural defenses of the body. They will be discussed later in the chapter. The second set of reasons has to do with the way diseases spread. Disease-causing microbes, or **pathogens** (path'ə jəns), must have a way of getting from one person to another. Some form spores that float through the air, but many do not. Fortunately for us, many pathogens cannot spread around quite so easily.

Some microbial diseases get started by accident. An example is a disease that begins when pathogens get into a cut or puncture wound. Lockjaw, or tetanus, is a disease that starts this way. Other diseases spread from person to person. These are **contagious** (kən tā'jəs) diseases. Such diseases may spread directly from person to person indirectly by things that people handle: food, water, clothing, and so on. Some of the pathogens that cause contagious diseases cannot live for long outside the human body. If they do not spread to a person, they die.

Some diseases are with us all the time, such as the common cold. This sort of disease is said to be **endemic** (en dem'ik). *Endemic* is a Greek word meaning "in the people." Malaria is an endemic disease in the tropical regions of the world. It is always present in those regions. When a disease starts to spread rapidly, it is said to be **epidemic** (ep ə dem'ik).

MAIN IDEA

Contagious microbial diseases are spread by air, water, food, contact, and vectors.

Robert Koch, an early microbiologist, established a procedure for determining if a particular disease is caused by a particular microorganism.

SCIENCE BACKGROUND

In addition to developing many of the methods of modern microbiology, Robert Koch also developed a number of great researchers. His students included Paul Ehrlich, who discovered an arsenic compound that cures syphilis; Fredrich Löffler, who discovered the diphtheria bacillus and who did some of the early work with filterable viruses; and Emil von Behring, who developed the diphtheria antitoxin. Élie Metchnikoff, who discovered the phagocytes, spent time in the labs of both Koch and Pasteur.



Influenza and measles often become epidemic diseases in the winter. There are always a few cases of the flu around. But when the number of cases increases rapidly, it is called an epidemic. Sometimes, epidemic diseases continue to spread until they involve a whole nation or the whole world. This situation is said to be **pandemic** (pan dem'ik), which means "all the people." The flu became pandemic in 1918. Millions of people around the world became ill that year.

Scientists are not sure what causes a disease to suddenly become epidemic. It is not known why there are flu epidemics in some years but not in others. One reason might be mutations. Viruses sometimes have mutations that increase their virulence. Flu viruses with increased virulence might be the cause of epidemics. Another cause might be that people lose their resistance to flu over the years. An epidemic might begin in a year when many people have lost their resistance. Perhaps both increased virulence and loss of resistance are causes of epidemics.

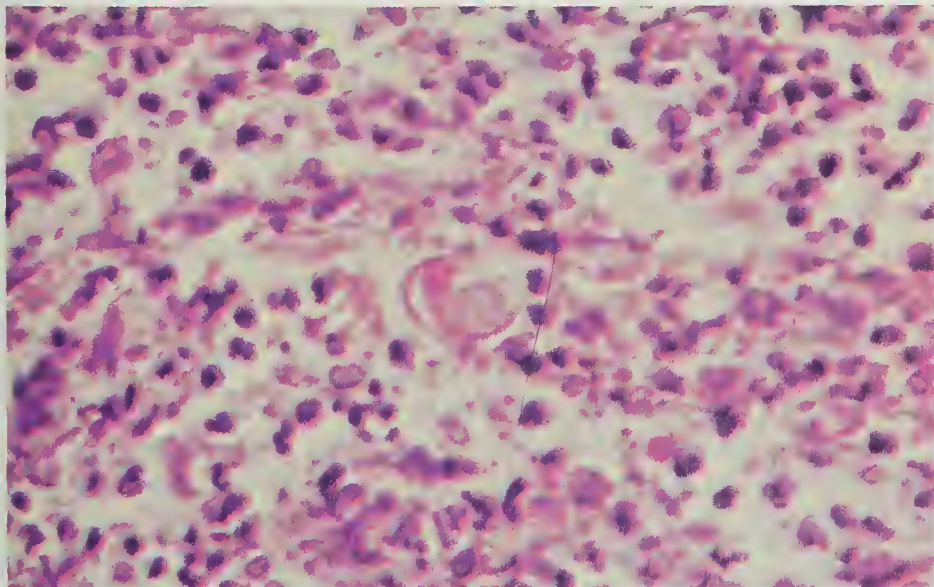
The flu is one of many **airborne diseases**, or diseases that spread through the air. Sneezes and coughs spray

many small droplets of moisture into the air. These droplets carry bacteria and viruses. Because the droplets are so small, they can float in the air for a long time. Other people may inhale the droplets and become infected by the pathogens in them. The droplets also settle on objects such as dishes, clothing, and furniture. People who handle these objects can become infected, too. In addition to the flu, other airborne diseases include measles, mumps, diphtheria, chicken pox, and fungus infections.

Some diseases are caused by pathogens in food and water that enter the body through the mouth. These are called **food-borne** and **waterborne** diseases. The majority of these diseases are caused by bacteria. Some are also caused by viruses and protozoans. Although they may spread to other parts of the body, these diseases are usually centered in the intestines. Pathogens use the food in the intestine to multiply and grow. Infectious organisms leave the body with the feces. These diseases are spread through food and water that has been contaminated with human wastes.

Bacteria of the genus *Salmonella* cause typhoid fever and several other food- and water-borne diseases. Often *Salmonella* diseases are spread by people called **carriers** (kar'ē ərs). These people are infected by *Salmonella* but do not show any signs of disease. They can continue to excrete the bacteria for years without knowing it. Frequently *Salmonella* diseases are spread by carriers who work in restaurants or in food-processing plants. If they fail to practice proper personal hygiene, their infection can be passed to many people through the food they handle.

Entamoeba histolytica is a pathogenic protist that invades the small intestine and causes a type of dysentery.



The bacteria and viruses that cause disease are often spread from one person to another as a result of coughing and sneezing.

SCIENCE BACKGROUND

It is the job of the epidemiologist to trace down carriers, as in salmonellosis. The Center for Disease Control (CDC) in Atlanta is the Mecca of epidemiology in the United States. The CDC is a branch of the U.S. Public Health Service

SCIENCE BACKGROUND

Legionnaire's disease represents a new mode of disease transmission, created artificially by modern society. The bacteria that cause this disease exist in nature but can only thrive in hot water. Water used for heat exchange purposes in commercial air-conditioning and in power plants is an ideal environment for these organisms. Inhalation or ingestion of sprayed droplets of this water seems to be the route of transmission.

MAIN IDEA

Venereal diseases are spread by sexual contact. Control of these diseases is hampered by failure to report infections.

SCIENCE BACKGROUND

Other venereal diseases, which are less widespread and less serious, include chancroid (bacterial); trichomoniasis (flagellate protozoan); pediculosis pubis (blood-sucking pubic lice); and venereal warts (viral).

Dysentery, cholera, infectious hepatitis, and viral gastroenteritis are examples of other diseases that spread like *Salmonella* disease. Dysentery has two forms. One form of it is caused by a bacillus. The other form is caused by an amoeba. Cholera is a serious bacterial disease, which has become rare in North America. In other parts of the world, especially Asia, cholera is endemic. Hepatitis is a virus infection of the liver. It is sometimes transmitted by shellfish that have been taken from waters contaminated by sewage.

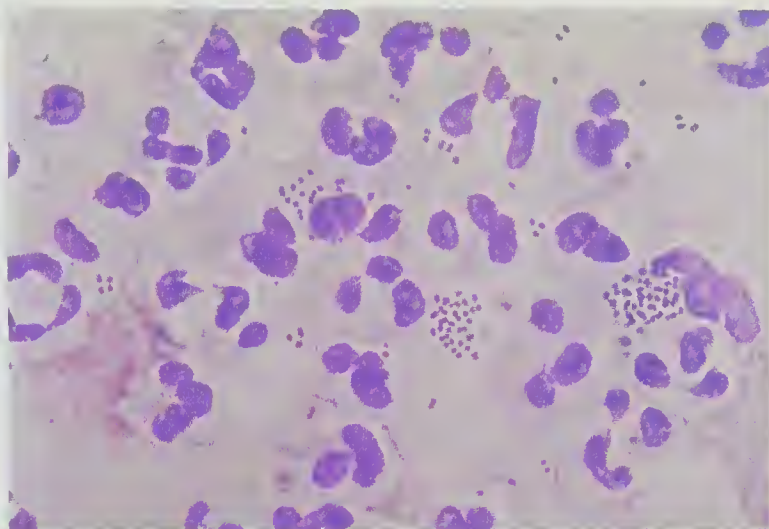
Some microbial diseases are spread by direct contact with infected material. These **contact diseases** can be spread from sores on the skin, mouth, or genital organs. Impetigo is a bacterial skin infection that is usually spread by contact. Chicken pox, small pox, and influenza are airborne diseases that can also be transmitted by contact. Diseases spread by contact with the genital organs form a special class. These are **venereal** (və nir'ē al) **diseases**.

A number of diseases are transmitted by fleas, ticks, flies, and mosquitoes. Transmitters such as these are called **vectors** (vek'tərs). The *Anopheles* mosquito is the vector of malaria. Sleeping sickness is transmitted by the tsetse fly. Both of these diseases are caused by protozoa. But bacterial and viral diseases are also carried by vectors.

Rats, squirrels, and other small animals are often infected by bubonic plague. Fleas are the vectors that transmit this disease from animals to humans. Yellow fever virus can only be carried to humans by a single type of vector. This vector is the *Aedes* mosquito. Viral encephalitis (en sef'ə lī'tis), an infection of the brain, can be spread by several types of insects.

17-2 Venereal disease Years ago diseases such as tuberculosis, diphtheria, and poliomyelitis were major health problems. Vaccination programs and antibiotics have dramatically reduced the occurrence of these diseases. Today these diseases have been replaced by the venereal diseases as our greatest health problem. Well over a million cases of venereal diseases are reported each year in North America. It is thought that many more cases go unreported. The World Health Organization estimates that more than 300 million venereal infections occur each year worldwide.

A large part of the venereal disease problem is that people are embarrassed by it. Venereal diseases are spread by sexual contact, and people do not like to talk about that. Those who are infected are sometimes afraid to seek treatment. This is unfortunate because two of the most common venereal diseases may be fairly easy to cure if they are



The causative agent of syphilis, Treponema pallidum and the causative agent of gonorrhea, Neisseria gonorrhoeae, are shown above.

treated early. It is also unfortunate because people who do not get treatment continue to spread the diseases to others.

The most common of the venereal diseases is **gonorrhea** (gon ə rē'ə). This has become the most widespread microbial disease in North America. Gonorrhea is caused by a bacterium. It is informally known as the gonococcus. The usual signs of this disease are a burning sensation and a discharge from the genital organs. But many people show no symptoms at all. This is one of the things that makes it so difficult to control this disease.

The second most widespread venereal disease is **syphilis** (sif'ə lis). This is a much more serious disease than gonorrhea. It kills 5 to 10 percent of the people who are infected by it. Syphilis is caused by a spiral bacterium, or spirochete. Signs of the disease begin to appear about 3 weeks after infection. A sore develops where the bacteria entered the body. The sore disappears after 2 more weeks. But that does not mean the disease has ended. The bacteria spread to other parts of the body. They may infect the brain, heart, or other organs. Signs of these new infections may not show up until many years after the first sore.

A third venereal disease is **genital herpes** (jen'ə təl hēr'pēz). This is caused by a herpes virus, a relative of the herpes virus that causes fever blisters in the mouth. Genital herpes is becoming increasingly common. The signs of genital herpes infection include fever and blisters on or in the genital organs. The disease sometimes disappears on its own. In other cases it keeps coming back repeatedly. Syphilis and gonorrhea can be treated with penicillin because they are caused by bacteria. Penicillin has no effect on genital herpes because it is caused by a virus. At this time there is no known treatment that will cure genital herpes.

SCIENCE BACKGROUND

An unfortunate complication of many of the venereal diseases is that they are readily transmitted to infants as they pass through the birth canal.

SCIENCE TERMS

pathogens
contagious
endemic
epidemic
pandemic
airborne diseases
food-borne diseases
waterborne diseases
carriers
contact diseases
venereal diseases
vectors
gonorrhea
syphilis
genital herpes
exotoxins
endotoxins
spreading factor

MAIN IDEA

Bacteria cause disease by producing toxins.

SCIENCE BACKGROUND

Endotoxins were so-named because it was thought that they were internal to bacteria. It has since been learned that endotoxins are actually fragments of the cell wall (lipopolysaccharides) of gram-negative bacteria, which are liberated if the bacteria disintegrate.

SCIENCE BACKGROUND

Bacterial exotoxins include a variety of enzymes in addition to the spreading factor (hyaluronidase). Collagenase dissolves connective-tissue fibers. Hemolysins rupture red blood cells. Leucocidins kill white blood cells.

ANSWERS TO CHECK YOUR FACTS

1. The common cold, flu, mumps, measles.
2. *Salmonella* diseases, dysentery, typhoid fever, cholera.
3. Gonorrhea.
4. Malaria, sleeping sickness, plague, yellow fever.
5. Impetigo, chicken pox, smallpox.
6. Epidemic.

17-3 How microbes cause disease We have seen that pathogens enter the body through air, food, and water. Other pathogens are carried by vectors and some are spread by sexual activity. Once pathogens enter the body, what do they do? How do they cause illness? We learned earlier that viruses do their damage by multiplying within the cells of their host. It is not the same with bacteria. Bacteria usually live in the spaces between cells, rather than inside cells.

Bacteria often cause illness by producing poisons. In some cases bacteria release poisons into their surroundings. These poisons are called **exotoxins** (ek sō tok'sōns). They are released by living bacteria. The bacteria that cause lockjaw, or tetanus, produce exotoxins. These bacteria usually enter the body through puncture wounds on the hands or feet. But the signs of the disease show up elsewhere. The muscles of the head and neck may become paralyzed. This is because the exotoxin travels through the bloodstream to reach these muscles.

Bacteria also form exotoxins when they grow in food. If meats, soups, milk, or cooked vegetables are left at room temperature, bacteria will grow in them. The bacteria may release exotoxins into the food. If this food is later eaten, serious illness may result. It is exotoxins, rather than the bacteria, that are the cause of many cases of food poisoning.

Certain types of bacteria contain poisons within their cells. These poisons, or **endotoxins** (en dō tok'sins), are not released until the bacteria die. Endotoxins released when bacteria die inside the body may produce severe reactions. High fever and dangerously low blood pressure are among these reactions.

Many bacteria produce destructive enzymes. One of these enzymes is known as the **spreading factor**. This enzyme dissolves the substance that makes our cells stick to each other. The bacteria can then spread between cells more easily. Some bacteria make enzymes that destroy the membranes of human cells. These enzymes kill blood cells and other types of cells.

CHECK YOUR FACTS

1. Give an example of an airborne disease.
2. Give an example of a food- or water-borne disease.
3. Which is the most common form of venereal disease?
4. Name a disease that is spread by vectors.
5. Name a disease that is spread by contact.
6. What term is applied to a disease that is spreading rapidly?

Defense Against Disease

17-4 Keeping the microbes out The best defense against disease is to keep infectious microbes out of the body. Public sanitation is a necessary part of this defense. Personal hygiene is also necessary. Proper disposal of sewage is important in keeping the pathogens of food- and water-borne diseases away from us. Elimination of vectors is another important step in slowing the spread of disease.

These points were well shown in the building of the Panama Canal. In the early years of construction, thousands of workers died of malaria, yellow fever, and typhoid fever. The workers' camps were unsanitary and swarmed with mosquitoes. People thought the diseases were carried by the warm, damp air of the tropics. But this is not true. The mosquitoes were the vectors of malaria and yellow fever. The unsanitary conditions in the camps were the cause of the typhoid fever. A campaign was started to clean up the camps and to get rid of the mosquitoes' breeding places. Within a few months the diseases died out, and construction of the canal went ahead.

Even if we keep clean, we cannot keep all pathogens away from our bodies. But the pathogens do not usually get inside. The skin acts as a barrier to keep them out. The membranes that line the mouth and the digestive system also form a barrier against pathogens. So do the membranes of the nose, windpipe, and lungs. All these membranes are called **mucous** (myü'käs) **membranes**. The mucus they produce traps pathogens and keeps them from getting into the tissues.

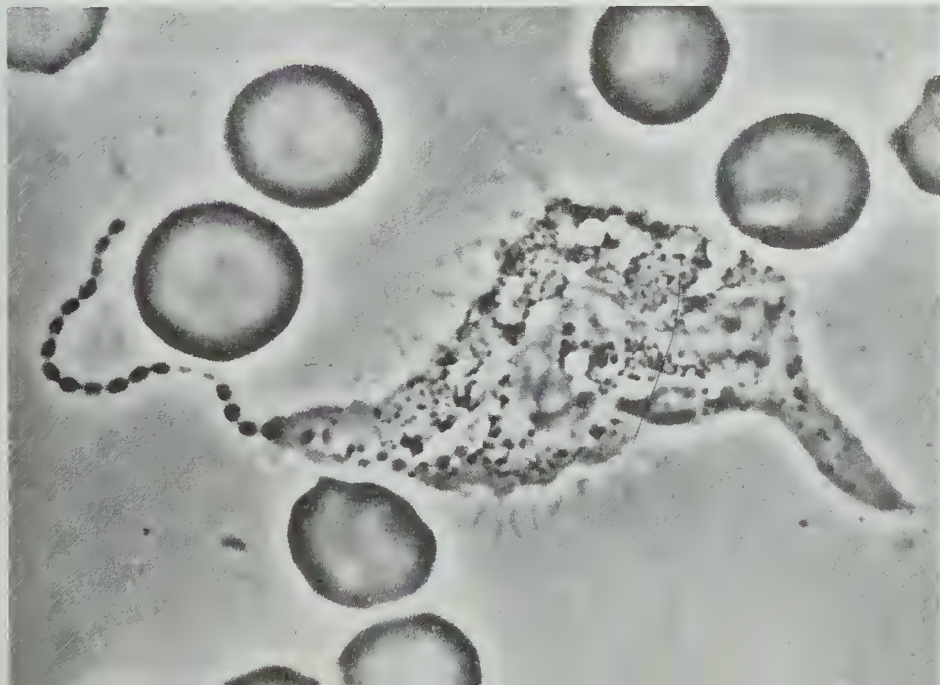
MAIN IDEA

Public health measures and the structural and cellular defenses of the body are important factors in forestalling infection.

SCIENCE BACKGROUND

Numerous microbes inhabit the human skin and the digestive tract. This normal flora seems to inadvertently aid in the defense against pathogens. Competition from the normal flora may prevent pathogens from establishing themselves in normal circumstances.

A white blood cell is engulfing a chain of bacteria in the photograph below. Red blood cells can also be seen.



SCIENCE BACKGROUND

In addition to leucocytes and macrophages, other phagocytes are found embedded in the walls of blood vessels in the spleen, the liver, and the bone marrow. These fixed phagocytes not only engulf microbes but also scavenge old red blood cells.

Pathogens enter the nose and lungs with every breath we take. These are trapped by the mucus. What happens after that? Coughing and sneezing eliminates some of this material. The mucous membranes of the windpipe and lungs are lined with millions of microscopic cilia, like those on a paramecium. These cilia constantly beat upward toward the nose. This action brings the mucus and the trapped pathogens up out of the lungs.

The body has other defenses besides the barriers formed by the skin and the mucous membranes. Some of the body fluids can slow the growth of pathogens or even kill them. For example, tears contain a substance that can kill some bacteria. Saliva also contains substances that kill some pathogens. Many of the pathogens we swallow with our food, along with those forced out of the lungs and then swallowed, are killed by acid produced in the stomach.

Skin, mucous membranes, tears, and stomach acid help to keep microbes out of the body. These are sometimes called the body's first line of defense against disease. But what if microbes get past the first line? There is a second line of defense formed by cells that destroy microbes. There are two kinds of these cells. One kind are certain types of white blood cells. The second is a type of cell called a **macrophage** (mak'rə fāj).

Some white blood cells and macrophages destroy pathogens by phagocytosis. These two types of cells are called **phagocytes** (fag'ə sīts) for this reason. The phagocytes constantly move through the blood and other tissues of the body, searching for invading pathogens. There may be as many as 100 thousand million phagocytes in the body of an adult human. No matter where pathogens enter the body, there is sure to be a phagocyte nearby.

MAIN IDEA

Immunity, which is mediated by antibody proteins, is a specific defense against infection.

SCIENCE BACKGROUND

Other antigenic substances that can provoke an immune response are pollen grains, tissue grafts, some synthetics, and animal parasites. Any substance that is of high molecular weight and is foreign to an individual's body is potentially antigenic.

17-5 Immunity We all know that people only get certain diseases once. If you have had measles, you will not get it again. Once you have had measles, you develop **immunity** (i myü'nə tē) to this disease. Immunity is a specific process. Immunity against the measles virus does not protect against any other disease. Immunity is the third line of defense against disease.

Immunity is caused by substances found in the blood and other body fluids. These substances of immunity are known as **antibodies** (an'tē bod ēz). The body produces many types of antibodies. Each type is effective against only one kind of disease. Antibodies are made by a special kind of white blood cell called a **lymphocyte** (lim'fə sīt). Lymphocytes are found in the blood, in the bone marrow, and in several of the body's glands.

Table 17–1 The Four Types of Immunity

<i>Type</i>		<i>Source</i>	<i>Duration</i>
NATURAL	Active	Develops as a result of infection. Pathogens, toxins, or other antigens cause lymphocytes to produce antibodies.	Many years or permanent.
	Passive	Antibodies passed from mother to infant during pregnancy or in colostrum.	Up to 1 year.
ARTIFICIAL	Active	Develops as a result of vaccination. Injection of dead or weakened microbes or weakened toxins causes lymphocytes to produce antibodies.	Many years. May need booster shots to be permanent.
	Passive	Injection of antibodies produced by another organism.	Several weeks.

SCIENCE BACKGROUND

Some antibodies interact with a group of blood proteins that are called complement. These complement-fixing antibodies initiate an enzymatic reaction by the complement proteins that leads to the lysis of cellular antigens.

Bacteria, viruses, and other pathogens contain chemicals that are foreign to the human body. The chemicals are completely different from any substance found in humans. These foreign substances are called **antigens** (an'tə jəns). When an antigen enters the body, it causes the lymphocytes to make antibodies. Antibodies are protein molecules with very complicated shapes. Each antibody has two or more pockets on its surface. The shape of these pockets matches the shape of a particular antigen. The antigen and the antibody fit each other like a lock and key. This is why there must be a different antibody for each disease, or each antigen.

Antibodies use their pockets to attach themselves to antigens. Each kind of antibody has pockets of a different shape. Each antibody has pockets that will fit only one kind of antigen. When an antibody attaches to an antigen, one of several things may happen. The antibody might cause several pathogens (antigens) to clump together. This keeps the pathogens from moving around and spreading through the tissues. It also makes it easier for phagocytes to capture the pathogens. Antibodies that cause clumping of microbes are called **agglutinins** (ə glü'tə nins).

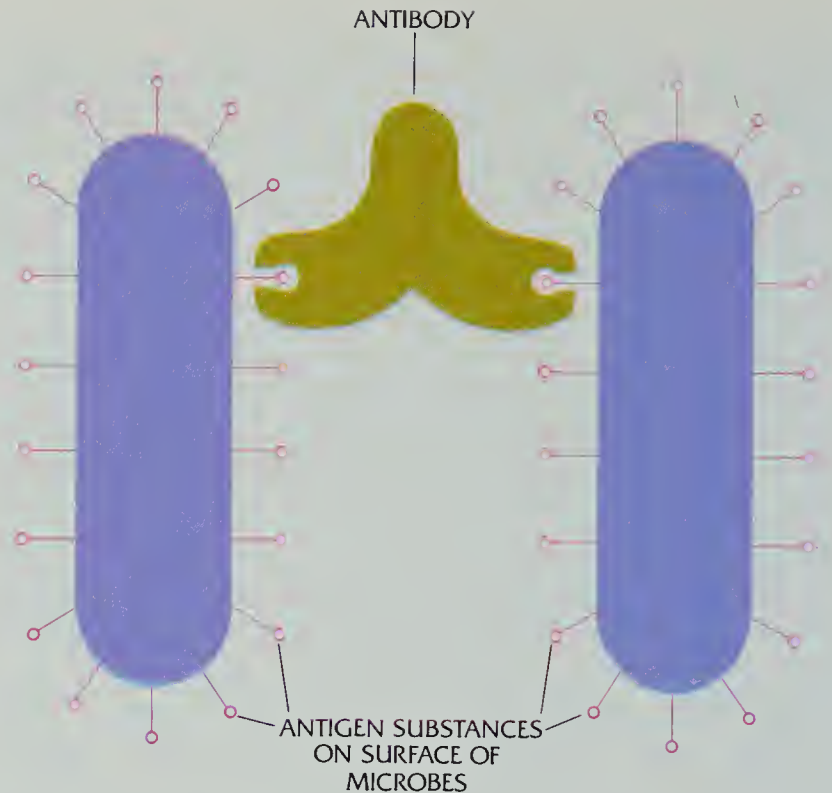


FIGURE 17-1 Antibodies bind to antigens on the surfaces of invading microorganisms, often making them susceptible to attack by phagocytes.

Some antibodies can cause the cell walls of bacteria to break open. The bacteria are killed by this. An antibody that acts in this way is called a **lysin** (lī'sin). Other antibodies attach themselves to toxins produced by bacteria. These are called **antitoxins** (an tē tok'sins). When a toxin is combined with an antitoxin, it can no longer do any harm.

When invading pathogens get past the body's first two lines of defense, the immune response begins. Lymphocytes begin to make antibodies within hours. But the pathogens may have already begun multiplying. As they multiply they make their toxins and cause their disease. It may take days or weeks before enough antibodies are made to eliminate all the pathogens. Finally, when all of them are gone, the symptoms of the disease disappear. But the lymphocytes do not forget.

The lymphocytes remember and wait. They circulate through the blood and the spaces in the tissues. Generally, if the same kind of pathogen enters the body a second time, the lymphocytes react immediately. They produce antibodies rapidly the second time. They also produce many more antibodies. The antibodies will eliminate the pathogen before it has a chance to multiply and spread. The microbes never get a chance to produce disease.

17-6 Natural and artificial immunity When a person is infected by the measles virus, lymphocytes react slowly the first time. The disease may last for a week or two. That same person might be infected with the measles virus many times thereafter, but the person never knows it. The lymphocytes react quickly. They eliminate the virus before any signs of the disease appear.

The process we have been describing is **active natural immunity** (i myü'nə tē). This means that a person's lymphocytes actively make antibodies after an infection. Active natural immunity lasts for many years or even a lifetime. There is also **passive natural immunity** to some diseases. This type of immunity is caused by antibodies an infant gets from its mother. This type of immunity is called passive because the infant's lymphocytes do no work.

The antibodies of passive natural immunity may pass from the mother to the infant during pregnancy. Or the antibodies may be passed to the infant in **colostrum** (kə los'trəm). This is a special type of milk produced during the first few days an infant is nursed. Colostrum contains many antibodies. Passive natural immunity gives protection only during the first year of life.

Sometimes natural immunity is not enough. Some diseases develop so quickly the first time that the lymphocytes cannot catch up. There may be no second chance for the lymphocytes to react more quickly. With dangerous diseases, we may need the help of artificial immunity. Like natural immunity, the artificial type can be either active or passive.

Active artificial immunity is produced by injecting either dead or attenuated microbes into a person. Even though the microbes are dead or weakened, they still act as antigens. Lymphocytes produce antibodies against the injected material. The lymphocytes remember it also. If an infection by the same microbe occurs after vaccination, lymphocytes go into action right away. Active artificial and active natural immunities work the same way. The lymphocytes do the work. The difference is that the natural form is started by an infection and the artificial form is started after vaccination.

Some diseases are caused more by exotoxins than by the bacteria themselves. In diphtheria, the bacteria grow only in the throat. But their exotoxin may spread through the whole body and cause serious disease. People need protection against the toxin more than they need protection against the bacteria. Artificial active immunity against the toxin can be produced. The diphtheria toxin can be weakened in the laboratory. If the weakened toxin is injected

MAIN IDEA

Immunity is acquired either naturally or artificially. It occurs in active and passive forms.

SCIENCE BACKGROUND

A weakened toxin is called a toxoid. Antibodies against either toxins or toxoids are called antitoxins, but these do not differ from other antibodies in their actions.

SCIENCE BACKGROUND

The transfer of passive immunity by colostrum is thought to be dependent on the ability of the newborn's intestine to absorb intact proteins (antibodies) without cleaving them to free amino acids.



Vaccines containing dead or weakened microorganisms are often prepared by inoculating fertilized chicken eggs with the microorganism.

into a person, it causes lymphocytes to make antibodies. The antibodies are able to destroy the diphtheria toxin. These antibodies will protect a person who later gets a diphtheria infection.

Active artificial immunity may last for many years. In some cases, booster shots of vaccine must be given a few years after vaccination. With boosters this type of immunity can be permanent.

Another type of artificial immunity is only temporary. This is **passive artificial immunity**. This type is produced by injecting antibodies into a person. The antibodies may be produced by another person or by an animal.

Passive artificial immunity takes effect as soon as the antibodies are injected. This method is used in crisis situations because it works fast. It is used in epidemics. It can also be used when a nonimmune person has already been exposed to dangerous disease. A person who gets a deep wound may be given tetanus antibodies in case tetanus bacteria are in the wound. Active immunity would not be fast enough to do any good in this case.

Passive artificial immunity lasts for about a month or less. Because pre-formed antibodies are injected, the lymphocytes do not do any work. Because they do no work, they do not remember. The lymphocytes are bypassed by injecting pre-formed antibodies. Once these antibodies have worn out, there is no more immunity.

To summarize, active immunity can be either natural or artificial. In both cases the lymphocytes in a person make antibodies. The lymphocytes will remember how to make the antibodies again, if needed. Passive immunity can also be either natural or artificial. In both cases the antibodies come from outside the body; from mother to baby (natural) or by vaccination (artificial). The person's lymphocytes are not involved. Passive immunity is temporary.

17-7 Chemicals against disease It is sometimes necessary to use drugs or chemicals to help the body fight off infection. This sort of treatment is called **chemotherapy** (kem ō ther'ə pē). The earliest use of chemotherapy goes as far back as 1630. It was then that quinine was discovered by Europeans as a cure for malaria. Quinine comes from the bark of a South American tree. The Indians of South America had been chewing quinine bark to treat malaria for hundreds of years.

A major advance in chemotherapy came in 1935. A family of chemicals called the **sulfa** (sul'fə) **drugs** was developed in Germany. Sulfa drugs are very useful because they kill a variety of bacteria. Sulfa drugs are also effective against some disease-causing protozoa. Sulfa drugs are sometimes dangerous. Although they were used for many years, they have now been largely replaced by safer drugs.

Today chemotherapy depends mostly on **antibiotics** (an tē bī ōt'iks). These are chemicals produced by microbes to kill other microbes. Sulfa drugs are artificial chemicals. Antibiotics are produced by living organisms. Fungi and bacteria of the soil are the main sources of antibiotics.

Penicillin, the best-known antibiotic, is produced by the fungus *Penicillium notatum*. This is a relative of the green molds found in blue cheese and spoiled fruit. Penicillin

SCIENCE TERMS

mucous membranes
macrophage
phagocytes
immunity
antibodies
lymphocyte
antigens
agglutinins
lysin
antitoxins
active natural immunity
passive natural immunity
colostrum
active artificial immunity
passive artificial immunity
chemotherapy
sulfa drugs
antibiotics

MAIN IDEA

Chemotherapy is the treatment of disease with antibiotics.

SCIENCE BACKGROUND

Many of the antibiotics on the market today are semi-synthetic. A naturally produced antibiotic is modified in the laboratory to enhance its microbicidal properties or to reduce its potential for causing allergic reactions.

ANSWERS TO CHECK YOUR FACTS

1. By the action of cilia.
2. Skin and mucous membranes.
3. Antigen.
4. Agglutinins.
5. Active artificial immunity.
6. They are made by microbes.



Alexander Fleming, shown above, isolated the first antibiotic from a mold called Penicillium.

SCIENCE BACKGROUND

Antibiotics that cannot be used in chemotherapy are widely used in research. Actinomycin-D inhibits the transcription of mRNA from a DNA template. This property is used to learn which cellular phenomena are dependent on the availability of mRNA.

was discovered in 1929 by Alexander Fleming. Fleming found a *Penicillium* mold growing on an agar culture of bacteria. He noticed that no bacteria were growing near the mold. Fleming isolated the mold and soon found that it produces a substance that kills bacteria. Later testing showed that this substance, penicillin, is safe to use in humans.

Fleming's discovery went unnoticed for many years. It was in the 1940s, during World War II, that penicillin finally came into use as a drug. Infected wounds were killing more soldiers than bullets were. An effective treatment for these infections was needed. Penicillin came into mass production and has been with us ever since.

In 1940 a second antibiotic, called streptomycin, was isolated from a soil microbe. Ever since then the search for new antibiotics has centered on soil microbes. Several thousand antibiotics have been found since 1940. However, not all of them are useful. Some of them kill humans just as well as bacteria. About 30 of these substances are now used in chemotherapy.

But why should soil microbes make antibiotics? Why do soil microbes kill each other? Soil microbes—whether they are fungi or bacteria—all use dead organic matter for food. They compete with each other for that food. Soil microbes make antibiotics as a way of eliminating the competition!

SCIENCE BACKGROUND

Some students may be confused initially by the similarity between antibiotic and antibody. Emphasize that antibodies are very specific, whereas antibiotics are usually effective against a variety of bacteria.

CHECK YOUR FACTS

1. How is mucus moved up from the lungs to the nose?
2. What parts of the body help to keep microbes out?
3. What is the name that applies to any foreign substance that enters the body?
4. What type of antibody causes microbes to clump together?
5. What type of immunity develops after vaccination?
6. Where do antibiotics come from?

SUMMARY

Microbial diseases can be transmitted in many ways. Pathogens can spread through air, water, food, and by contact. Some diseases are spread by vectors. Modern medicine and sanitation have eliminated many diseases, but venereal diseases are increasing. They are spreading because people do not report their infections. Bacteria produce disease by releasing toxins and destructive enzymes. While vaccines and treatments against many diseases are available, the best way to prevent disease is to keep dangerous pathogens out of the body.

REVIEW QUESTIONS

1. What is a carrier?
2. Explain the differences between endemic, epidemic, and pandemic disease.
3. Explain how *Salmonella* disease is spread by carriers.
4. What is the difference between an exotoxin and an endotoxin?
5. Explain the difference between the two types of natural immunity.
6. Explain the difference between the two types of artificial immunity.
7. How do antibiotics differ from other drugs used to treat disease?
8. What is the difference between an antibody and an antibiotic?
9. What advantage is it for soil bacteria and fungi to make antibiotics?

ANALYSIS AND APPLICATION

1. Viruses differ from bacteria in how they cause disease. Explain.
2. Name the body's three lines of defense against disease.
3. It is said that lymphocytes have a memory. Explain.

ANSWERS TO REVIEW QUESTIONS

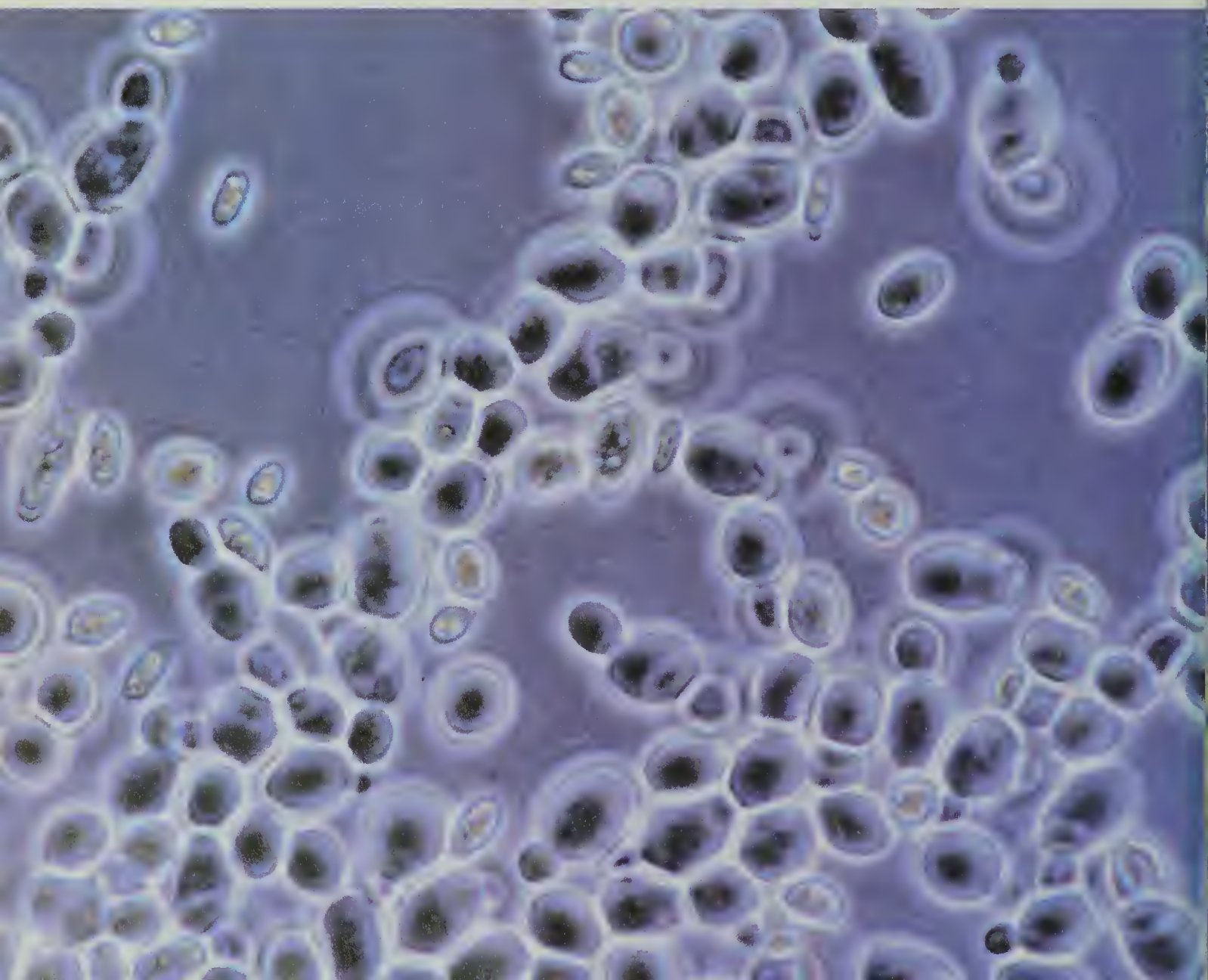
1. A person who is infected by a microbe but shows no signs of disease.
2. Endemic—low but constant incidence; epidemic—rapidly increasing incidence; pandemic—national or international high level of incidence.
3. Carriers working in restaurants and food-processing plants may contaminate the food they handle.
4. Exotoxins are secreted by living bacteria; endotoxins are liberated when some bacteria die.
5. Active follows infection; passive is due to maternal antibodies.
6. Active is by vaccination with dead or attenuated microbes or with toxoids; passive is by injection of antibodies.
7. Antibiotics are made by living organisms.
8. Antibodies are made by the lymphocytes of humans and other animals; antibiotics are made by microbes.
9. To eliminate competing microbes.

ANSWERS TO ANALYSIS AND APPLICATION

1. Viruses do their damage by multiplying intracellularly. Bacteria cause disease by secreting enzymes and toxins.
2. Structural defenses, phagocytes, and specific immunity.
3. After a first infection, lymphocytes retain a memory of how to make antibodies against that specific microbe. This permits rapid destruction of the microbe if a second infection occurs.

Investigation 32 from *Laboratory Investigations in Biology* can be done with this chapter.

18 Microbes Work



OBJECTIVES

- To appreciate the importance of decomposition and recycling by microbes
- To understand the metabolic versatility of microbes
- To understand that microbes are necessary for two stages of cheese manufacture: curdling and ripening
- To explain alcoholic fermentation
- To understand that microbes produce vitamins and other food supplements
- To discuss some examples of industrial microbiology
- To discuss biological sewage treatment
- To explain that microbial fermentation can be a source of valuable fuels

for People

18-1 Useful microbes We hear so much about microbes that cause disease, but we forget that only a few microbes are pathogenic. There are many thousands of microbe species. Most microbes perform useful functions in nature. Life would not be possible without microbes.

Some of the useful activities of microbes were mentioned in earlier chapters. Bacteria and fungi cause the decay of dead plants and animals. Imagine what would happen if this were not so. The bodies of dead organisms would pile up. The chemicals of life would be locked up in this dead material. New organisms might not find enough food to nourish themselves. The microbes of decay remove the remains of dead organisms. In addition, they release the chemicals in these dead organisms. Useful chemicals are returned to the water and soil. They are then available to living organisms to use.

The chemicals that microbes release from dead organic matter can be used again by plants. Plants, in turn, serve as food for animals. Plants and animals die eventually. Bacteria and fungi decompose their remains. The chemicals of life are released to be used again by new generations of plants. This is the recycling of the chemicals of life. The recycling is made possible by microbes.

Microbes perform other useful functions in nature, too. We learned earlier about the importance of microscopic algae. As small as these cells are, they perform much of the photosynthesis that occurs on earth. The floating algae of the lakes and oceans form the food for all other organisms of the water. In the future these algae may be used as food for people, too.

MAIN IDEA

The majority of microbes perform useful functions in nature.

SCIENCE BACKGROUND

A good demonstration of the metabolic versatility of microbes is given by the Winogradsky column. This is a glass cylinder packed with soil or pond mud along with a carbon source and a sulfur source. Various bands of microbial growth will develop as a function of depth, aeration, lighting, and proximity to the sulfur source. Consult a microbiology text for details.



Microbes and other decomposers break down dead organic matter and release the chemicals for reuse by the living world.

Microbes are responsible for nitrogen fixation. In this process, bacteria and blue-green algae trap the nitrogen gas of the atmosphere. These microbes convert nitrogen to nitrates, which are used by plants to make their proteins. Animals get their proteins from plants. In other words, nitrogen fixation by microbes is the basis of the world's protein supply.

Fermentation, decay, nitrogen fixation, and photosynthesis are just a few of the many reactions carried on by microbes. There is probably at least one type of microbe that can use each of the chemicals that exist in nature. There are even microbes that can metabolize things like iron and petroleum. Experiments have been conducted with bacteria that can use petroleum as food. Perhaps these microbes will be put to work in cleaning up oil spills.

Every substance in nature can be used as food by some microbe. Microbes nourish themselves in all possible ways. Some require oxygen; others prefer to live without oxygen. Seeing the many things that microbes can do, people have learned to put microbes to work. Microbes are used today in many manufacturing processes.

18–2 Microbes in the dairy industry People have been making cheese and fermented milk products, such as yogurt, for thousands of years. People have always known that milk is a very nutritious food. Before the days of refrigerators, milk could not be kept for more than a day or so. Cheese and fermented milk products were first made as a way of keeping milk. Cheese can be kept without refrigeration for much longer than milk can.

Microbes play a part in the production of many dairy products. Besides cheese and yogurt, microbes help to produce butter, buttermilk, and sour cream. Microbes give these dairy products their special flavors. Butter can be made without the action of microbes. Such butter, however, is very bland and unappealing.

Butter is usually made by adding “starter” bacteria to cream. These bacteria produce lactic acid and other ingredients that add flavor to the cream. The cream is later cooled and then churned. Churning causes the microscopic particles of butterfat in the cream to stick together to form the butter. The liquid that remains after churning is buttermilk.

Buttermilk can also be made by adding bacteria to pasteurized fat-free milk. The bacteria produce chemicals that give the buttermilk its flavor. Buttermilk produced in this way is called cultured buttermilk.

Microbes play an even greater part in the making of cheese. Not only do they give cheese its flavor, but they are also part of the cheese-forming process itself. Hundreds of varieties of cheeses are produced around the world. Most are made from whole milk, others from skim milk. Goat’s milk is sometimes used, too. But most of the differences among cheeses are caused by microbes. The action of microbes gives cheeses their flavors.

The making of cheese begins with the addition of lactic acid bacteria and enzymes to milk. The enzymes and the acid produced by the bacteria cause **curdling** (kèrd’ling) of the milk. Curdling is the separation of the milk solids from the liquid. The lumps of solids that form are called **curd** (kèrd). The curd consists of protein and fat along with small amounts of vitamins, minerals, and lactic acid. The amount of fat in the curd depends on the type of milk used. Curd made from skim milk has a low-fat content.

After the curd has formed, a liquid known as **whey** (hwā) is left behind. Whey consists mostly of water. It also contains lactose, or milk sugar. Whey used to be discarded, often causing pollution of streams near dairies. Whey is now used in other manufacturing processes. This saves money and prevents pollution at the same time.

MAIN IDEA

Microbial action is essential to the production of many dairy products, especially cheese.

SCIENCE BACKGROUND

It is probable that the first cheese was produced far back in history as a result of an accident. It is hypothesized that someone attempted to store milk in a tied-off sheep’s stomach, as is often done with wine by herders. The enzyme rennin produced by the stomach along with microbial action on the warm milk resulted in the first cheese.

SCIENCE BACKGROUND

The enzyme rennin acts along with bacterially produced lactic acid to cause curdling of milk. Rennin was long obtained from the stomachs of slaughtered animals. It is now produced by special bacterial cultures.

In cheese making, milk is first curdled by bacterial activity. Most cheese is then allowed to ripen for a time. Ripening is accomplished by either bacteria or fungi.



In making cheese, the curd is separated from the whey by straining. After the curd is drained, it is usually salted. The curd can be used in this fresh condition as cottage cheese. Fresh curd can also be blended with cream to make cream cheese. Cottage cheese and cream cheese are called unripened cheeses because they are made from fresh curd.

Most varieties of cheese require a period of ripening. The ripening is accomplished by bacteria or fungi. These microbes act on the curd over a period of time to produce special colors, flavors, and textures. Cheeses like cheddar and Swiss are ripened by bacteria. Blue cheese and Camembert are ripened by fungi of the genus *Penicillium*. Each type of cheese is ripened by a different microbe. Ripening requires less than a month for some soft cheeses. Hard cheeses may ripen for over a year.

18-3 *Microbes in the food and beverage industries*

One of the best-known activities of microbes is the production of wine, beer, and other beverages. The fermentation of sugar by yeasts is the source of all alcoholic beverages. Fermentation is the splitting of sugar molecules in the absence of oxygen. This is how yeasts obtain their energy when they grow without oxygen. Alcohol and carbon dioxide are produced as by-products.

Yeasts are found in many places. Some grow naturally on the skins of grapes and other fruits. When fresh grapes are crushed, yeasts from the skins mix with the sugar in the grape juice. The yeasts ferment the sugar to alcohol. This is how wine is produced.

Beer, whiskey, and other liquors are produced by fermentation of grains. Barley is used in making beer. Corn, rye, and wheat are used in making whiskeys. These grains contain a great deal of starch but very little sugar. Yeasts cannot ferment starch. To make alcohol from grain, the starch must first be converted to sugar. This is done by cooking the grain and adding starch-digesting enzymes.

Wine is produced as a result of the fermentation of fruit sugars by yeasts. The alcohol is a by-product of the fermentative process.

MAIN IDEA

Microbial fermentations are involved in the production of alcoholic beverages, bread, and other foods.

SCIENCE BACKGROUND

Yeasts convert all the available sugar in grape juice into alcohol until an alcohol concentration of about 12 percent is reached. The yeasts are inactivated at higher concentrations. Wines with alcohol concentrations exceeding 12 percent are artificially fortified with alcohol.





Pickles are made by preserving cucumbers in a brine-vinegar solution. Microbes are responsible for the souring that occurs.

The enzymes convert the starch to sugar. The yeast ferments the sugar to alcohol and carbon dioxide. A liquid containing small amounts of alcohol and carbon dioxide is produced. This liquid can be filtered and bottled as beer. In the production of whiskey, additional steps are needed to increase the alcohol content.

Fermentation of sugar by yeasts is also part of the bread-making process. When yeast is added to bread dough, it acts on the sugar in the dough. Alcohol and carbon dioxide are produced. The carbon dioxide forms bubbles that cause the dough to rise. These carbon dioxide bubbles are what make all the little holes we see in bread. The alcohol produced by the yeasts boils off when the bread is baked.

SCIENCE BACKGROUND

In producing beer from barley, the grain must first be *malted*. It is soaked and allowed to germinate and then dried. The germinated seed contains a starch-digesting enzyme that splits the starch in the grain to sugar. The sugar is then fermented by yeasts.

Some types of bacteria can use alcohol as their food. These bacteria convert alcohol to acetic acid. This is the sour-tasting substance that gives vinegar its flavor. Vinegar was first made by allowing such bacteria to turn some wine sour. Today vinegar is made from alcohol from many different sources.

Microbes play a role in the production of several foods besides cheese, bread, and vinegar. Pickles, green olives, and sauerkraut get their special flavor by the action of microbes.

Many microbes produce vitamins that humans require for good nutrition. Bacteria that live normally in the human intestine are active producers of vitamins. These bacteria provide much of our requirements for vitamin K, biotin, and the B vitamins. Many of the vitamins sold in drugstores are produced by microbes. Yeasts also produce many vitamins. People who need extra vitamins sometimes get them by eating dried yeast.

Microbes produce useful products from nonuseful materials. Paper mills, dairies, and oil refineries make wastes that can be used by microbes. Bacteria, yeasts, and single-celled algae use these waste products as food for their growth. They make many proteins and vitamins as they grow. These nutrients can be used as food supplements.

Food supplements made by microbes have been used in raising livestock, such as cattle and chickens. In the future these food supplements may be used to help people. There is a serious shortage of protein foods in some parts of the world. Proteins made by microbes from industrial wastes can help with this problem. Using up these factory wastes also helps to cut down pollution. These waste products might otherwise be dumped into rivers. Using microbes this way will help hungry people and will help prevent pollution at the same time.

18-4 Microbes in manufacturing processes Microbes are involved in the manufacturing of many products other than foods and beverages. One example is the manufacture of leather. The production of leather from raw animal hides is called **tanning** (tan'ing). Several types of bacteria are used in the tanning process. The hides are first soaked, and then excess flesh is scraped off. Bacteria are then used to remove the hair from the hides. Finally the hides are soaked again in large tanks. Bacteria produce enzymes that digest some of the fibrous materials in the hides. This leaves the soft, flexible material we call leather.

Bacteria serve a similar function in the production of linen. Linen is made from fibers taken from the stems of flax plants. The separation of the useful fibers from the other material in the flax stems is called **retting** (ret'ing). Cut flax stems are placed under water. As materials dissolve from the stems, the water becomes a good growth medium for bacteria. The bacteria consume the substances that glue the fibers together in the stem. After about two weeks the separated fibers are removed and washed. When dry, they are woven into linen fabric. A similar process is used in preparing hemp fibers for making rope.

MAIN IDEA

Microbes are employed in a variety of industrial processes because of their various abilities to transform organic materials.

SCIENCE BACKGROUND

In modern leather tanning, specific microbial enzymes are used in place of random microbial action in soaking vats. Keratinase is used to dehair the hides, and collagenase is used to remove connective-tissue fibers.



The fibers in the stems of flax plants are separated through the action of bacteria. The dried fibers are then woven into linen fabrics.

Microbes can use almost any natural substance as food. Microbes can convert substances from one form to another. We have already seen an example of this. Bacteria convert alcohol to acetic acid, or vinegar. In so doing, the bacteria get energy for their growth. The ability of microbes to convert substances from one form to another makes them very useful in the chemical manufacturing industry.

Fungi are used to produce several chemicals that are used in the making of paints. Enzymes obtained from bacteria and yeasts are used in industrial processes such as paper making. Microbes produce several solvents that are used in the plastics industry.

SCIENCE BACKGROUND

Among the therapeutics produced with the help of microbes are analogs of steroid hormones, such as cortisone and the sex hormones. These are used in treatment of hormone imbalances and in arthritis.

Perhaps the greatest use of microbes is in the production of drugs and medicines. Microbes are the source of antibiotics. This is only one of their contributions to the drug industry. Bacteria are used to produce several vitamins, such as vitamins B₁, B₁₂, and C. Bacteria and fungi also help to produce medicines. Among these are drugs used in treating blood diseases and arthritis.

Microbes are also put to work on the farm. Dairy cattle are often fed on material called **silage** (sī'lij) during the winter. Waste plant-materials from the farm are packed into a silo. Cornstalks are frequently used for this purpose. Fresh cornstalks do not make very nutritious food. The cornstalks are shredded and allowed to stay in the silo for several months. During this time microbes ferment the plant material. They convert undigestible materials into useful nutrients. The silage is fed to the livestock during the winter months when other foods are not available.

The use of microbes to process silage is an old practice. There are also some newer ideas about using microbes in agriculture. Microbes that cause diseases in insects are beginning to be used to protect crops. Insects do much damage to food crops. Formerly, poisonous chemicals were used to rid farmlands of these pests. But the use of disease-causing microbes is a better idea. Such microbes usually cause disease in only one or a few types of insects. There is little danger to pets, people, or wildlife in spreading such microbes on crops. By contrast, the use of chemicals to kill insects is very dangerous. These chemicals can kill birds, earthworms, and useful insects. Disease-causing microbes act only on the destructive insects.

Some fungi produce a chemical that stimulates plants to grow faster. This chemical is produced naturally by plants to control their growth. It also causes plants to make more seeds or more fruit. Having this chemical produced by fungi makes it available for use on farms. It has been used to increase the yield from fruit trees and other crops.

Waste plant-material stored in silos is converted into nutritious animal feed through the fermentative activity of microbes.

SCIENCE BACKGROUND

Bacillus thuringensis is marketed commercially as an insecticide. This bacterium is effective against a variety of insect pests but is not harmful to higher animals.



MAIN IDEA

The use of microbes in waste processing and fuel production mimics the decomposer and recycling actions of microbes in nature.

18-5 Microbes in waste treatment and fuel production Microbes in nature decompose the remains of dead organisms. They recycle the chemicals of life. Having observed this in nature, people are learning to make microbes do similar work for our own purpose. Microbes are now being used in sewage-disposal processes. This idea is similar to the role of microbes as decomposers in nature. A newer and even more important idea is the use of microbes to convert wastes into fuels. This idea is similar to the role of microbes in recycling chemicals in nature.

Each day our cities produce many millions of litres of sewage. Something must be done with this sewage. If it is discharged into lakes or rivers, it will cause pollution. The water in these lakes and rivers could not be used for anything else. The sewage must be processed first to remove the polluting materials from it. Several modern methods of sewage treatment use microbes to eliminate pollution. These methods are called **biological sewage treatment**.

Sewage treatment always begins with the removal of coarse solid materials. This is done by allowing the sewage to pass through screens. It can also be done by allowing the sewage to settle in large holding tanks. In either case the liquid still contains many tiny particles and dissolved chemicals. These substances must be removed before the liquid is passed into a lake or river.

One method for removing the particles and chemicals uses a **trickling** (trik'ling) **filter**. This device consists of a large tank filled with small stones and pebbles. Aerated sewage is allowed to trickle through the bed of stones. When a trickling filter is first started, the stones are clean. After a few weeks of passing sewage through it, the stones become coated with a variety of microbes. From that time on, the microbes do the work of sewage treatment. As long as the sewage passing through is aerated, the microbes grow actively. As the microbes grow they use the particles and chemicals in the sewage as food. The water that leaves the bottom of the filter is fairly clean.

A second method of biological sewage treatment uses two tanks. Sewage is pumped first into a tank through which air is bubbled. Microbes grow rapidly in this tank. They use the oxygen to digest the materials in the sewage. The sewage is then pumped into a second tank and allowed to stand. The microbes and the remaining small particles settle to the bottom. The material that accumulates on the bottom of this tank is called **activated sludge** (ak'tə vā tid sluj).

SCIENCE BACKGROUND

The microbial coating on the rocks of a trickling filter is referred to as a zoogeleal film. The zoogelea consists of a mixture of bacteria, fungi, protozoa, and algae embedded in a mucoid matrix. Bacteria predominate.



In modern sewage-treatment plants (top) microbes are used to remove pollutants from waste water before it is discharged into bodies of water. Activated sludge (bottom) is rich in microbes and can be added to untreated sewage to remove pollutants.



SCIENCE BACKGROUND

Gasohol typically consists of 90 percent unleaded gasoline and 10 percent ethanol. Pineapple is a desirable source for gasohol production because of its high photosynthetic efficiency, its high sugar content, and its ability to grow well in semiarid conditions that might not be productive for other purposes.

Activated sludge contains many microbes. Some of this activated sludge is returned to the first tank (the one that is aerated). The addition of the activated sludge causes the next batch of sewage to be digested much faster. The microbes in the activated sludge do the work quickly. There is no need to wait for new microbes to grow in each batch of sewage.

Only a part of the activated sludge produced in this process is reused. The remainder is available for other uses. Activated sludge can be removed from the settling tank and dried. This dried material makes an excellent fertilizer.

Activated sludge can also be used to produce **methane** (meth'ān). Methane (CH_4), which is also called natural gas, is an excellent fuel. Burning methane produces no pollution. To produce methane, activated sludge is pumped into a sealed tank. The microbes in the sludge are forced to grow without oxygen. Under these conditions the microbes ferment the remaining sewage particles in the sludge to methane.

SCIENCE TERMS

curdling
curd
whey
tanning
retting
silage
biological sewage treatment
trickling filter
activated sludge
methane
gasohol

ANSWERS TO CHECK YOUR FACTS

1. Microbes exhibit all forms of nutrition.
2. Dairy products, bread, green olives, sauerkraut, pickles, wine, beer.
3. Vitamin K, biotin, and vitamins of the B group.
4. Yeasts.
5. In the production of silage and growth-stimulating chemicals, and as insecticides.
6. Fertilizer and fuel.
7. Grain, sugarcane, pineapple plants and other plant materials with a high carbohydrate content.

Alcohol produced by the fermentation of plant material by microbes can be used to make gasohol.

The use of microbes to convert sewage into fuel is a fairly new idea. It has been tried on a small scale and found to be successful. Perhaps the future will bring greater use of this idea. It will certainly help with our country's ever-growing need for new sources of energy.

Sewage is not the only material that microbes can convert into clean-burning fuel. Any plant matter that contains much starch or sugar can be fermented to alcohol. The process is much the same as in the production of alcoholic beverages. If the starting material contains sugar, yeasts can ferment it directly to alcohol. If the starting material contains starch, the starch must first be converted to sugar.

A wide variety of plant materials can be used to produce alcohol. Examples are surplus grain, sugarcane, and waste parts of pineapple plants. Alcohol as a fuel can be used in many ways. Perhaps the most useful of these is the production of **gasohol** (gas'ə hōl). Gasohol is made by mixing alcohol with gasoline. It is used to power automobiles, trucks, and farm machinery. Using gasohol as auto fuel will help to conserve the earth's scarce petroleum resources. Cars that burn gasohol may also give off less pollution than cars that burn ordinary gasoline.

Fertilizer and fuel from sewage, fuel from surplus crops—all of this is accomplished by microbes. Processing wastes to recover useful materials is a powerful idea for the future. Recycling things this way reduces the wasting of precious natural resources. Microbes can help us with this task.



CHECK YOUR FACTS

1. How do microbes nourish themselves?
2. What foods do microbes help to produce?
3. What vitamins do humans get from bacteria that live in the intestine?
4. What type of microbe ferments sugar to alcohol?
5. To what uses are microbes put in agriculture?
6. What useful materials are produced by biological sewage-treatment processes?
7. What materials can be used to make alcohol for fuel purposes?

SUMMARY

Microbes in nature perform many useful functions. They decompose dead organisms and recycle chemicals. Microbes nourish themselves in all possible ways. They can use almost any chemical as food. Having observed all these things that microbes do naturally, people have put microbes to work. Microbes assist in the production of a wide variety of foods. The use of microbes in waste recycling processes is a growing idea.

REVIEW QUESTIONS

1. Why is it important that microbes decompose the remains of dead plants and animals?
2. What two steps in the cheese-making process involve the action of microbes?
3. What must be done before yeast can convert grain into alcohol?
4. How do microbes act in the tanning of leather?
5. What is silage? How is it made?
6. Why is the use of microbes to kill insect pests a better idea than the use of chemical poisons?
7. What materials can microbes convert into food supplements?
8. What are two methods of biological sewage treatment?
9. How does a trickle filter work?
10. What is the advantage of using gasohol as a fuel?

ANALYSIS AND APPLICATION

1. What makes microbes useful in manufacturing processes?
2. How are the industrial uses of microbes similar to the actions of microbes in nature?

ANSWERS TO REVIEW QUESTIONS

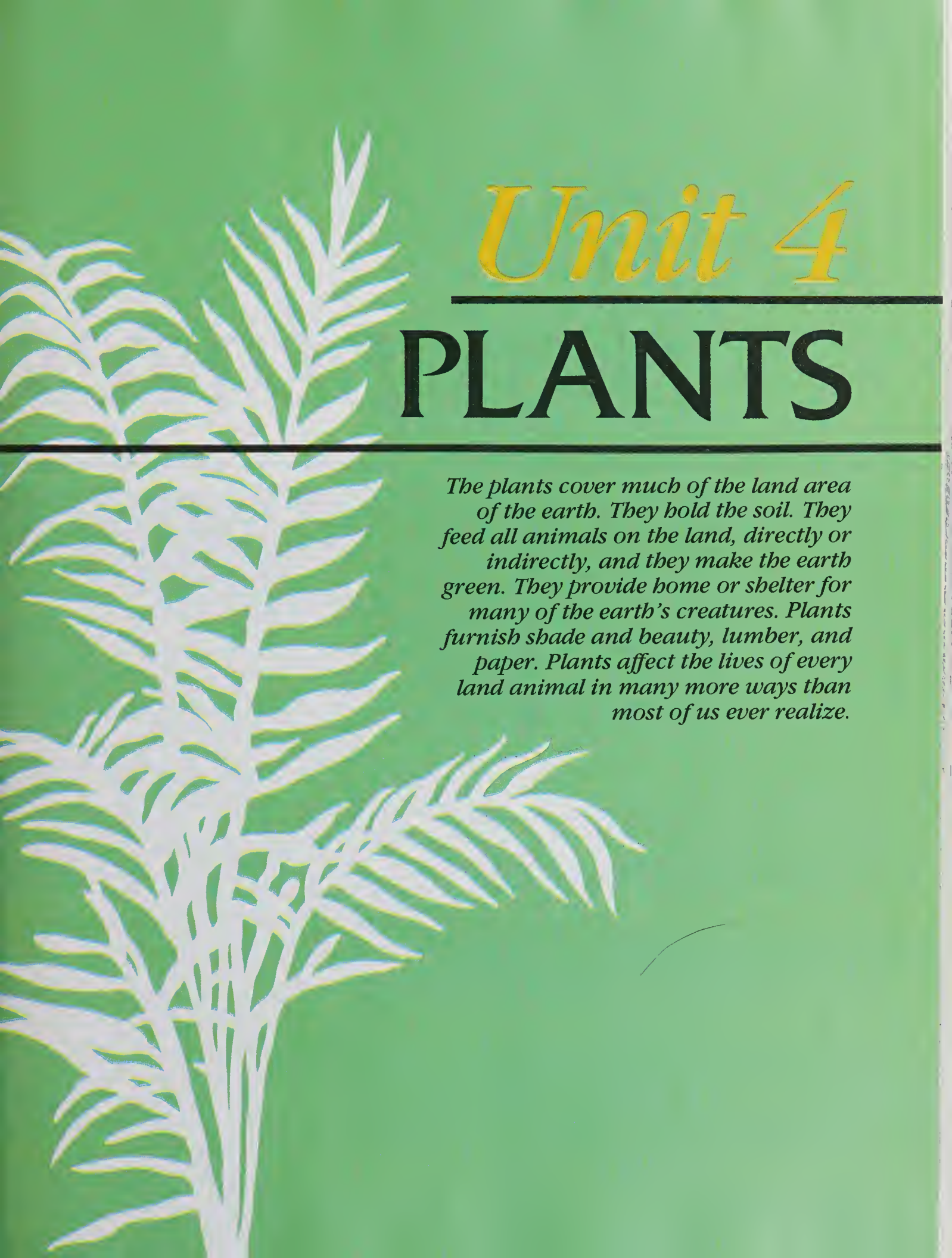
1. Chemicals are released to be used again.
2. Curdling and ripening.
3. The starch in the grain must be converted to sugar.
4. Microbes remove the hair and remove fibers to make the hide flexible.
5. Silage is livestock feed that is made by the action of microbes on shredded plant materials.
6. Such microbes are usually harmless to all but the target species.
7. Whey from dairies, and wastes from paper mills and oil refineries.
8. The trickling filter method and the activated sludge method.
9. Microbes, which coat the stones of the filter, consume the organic matter in the sewage.
10. Conservation of energy resources and, perhaps, reduced air pollution.

ANSWERS TO ANALYSIS AND APPLICATION

1. Microbes engage in all forms of nutrition and metabolic conversions.
2. Fermentations and sewage treatment are similar to decomposition. Microbial synthetic processes reflect the role of microbes in natural recycling.

UNIT 3 REVIEW

1. Organisms that are called algae are found in three different kingdoms. The blue-green algae are in kingdom Monera; the golden algae and diatoms are in kingdom Protista; and the red, green, and brown algae are in kingdom Plantae. Explain why this is so.
2. Discuss the various ways in which protists nourish themselves.
3. Many microbes share a common means of surviving through difficult periods. How? Give examples from several different groups of microbes.
4. Two men were important pioneers in the study of microbes. Who were they? Discuss their contributions.
5. Make a list of the useful activities of microbes. Which of these occur in nature? Which are uses that humans have found for microbes?
6. Discuss the various ways in which microbes cause disease. Which groups of microbes include disease-causing organisms?
7. What are the useful activities of algae? What useful products do algae make?
8. Microbes exist in both eucaryotic and procaryotic forms. They occur as unicellular, colonial, and multicellular organisms. Discuss the meaning of these terms. Give examples for each category. Where do viruses fit in?
9. In what ways are algae similar to fungi? In what ways are they different?
10. Discuss the body's defenses against disease.



Unit 4

PLANTS

The plants cover much of the land area of the earth. They hold the soil. They feed all animals on the land, directly or indirectly, and they make the earth green. They provide home or shelter for many of the earth's creatures. Plants furnish shade and beauty, lumber, and paper. Plants affect the lives of every land animal in many more ways than most of us ever realize.

19 *The Bryophytes*



OBJECTIVES

- To understand that the size and habitat of bryophytes relates to their lack of a vascular system
- To appreciate the role of pioneer plants
- To understand the nature of typical mosses
- To explain the life cycle of a typical moss
- To identify a liverwort, such as *Marchantia*

19-1 General characteristics The bryophytes (division Bryophyta) are the simplest of the true plants. They are thought to be descendants of green algae, which they resemble at certain stages of their life.

The bryophytes include the mosses, liverworts, and hornworts. Most are low-growing plants and are seldom recognized. The most unique characteristic of the bryophytes is their lack of a **vascular** (vas'kyə lər) **system**, which transports materials through the stems and leaves of higher plants. Their lack of a vascular system explains why they are low-growing plants. A plant can grow tall only when it has an efficient system for transporting materials within the plant.

19-2 Where are bryophytes found? Most bryophytes live in moist, tropical, and semitropical forests. However, there are many bryophytes—especially the mosses—that survive in moist temperate habitats. A few even survive in dry regions.

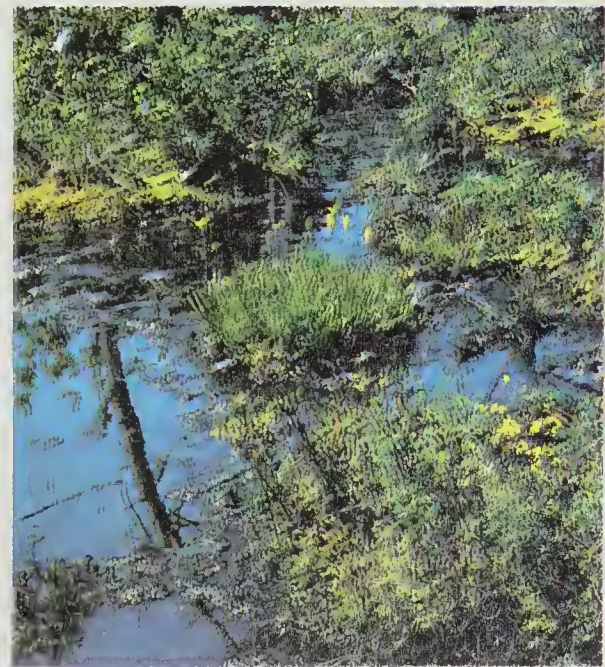
The bryophytes are often **pioneer** (pī ə nir') **plants**, or plants that are the first to establish themselves in areas where there are no plants. For example, when there is enough moisture, they can establish themselves on bare rock, such as lava from volcanoes. Several different bryophytes are important pioneer plants in many burned-over forest areas. They help prevent erosion, or the washing away of soil, until larger plants have time to take over.

One group of mosses, called *Sphagnum*, grows in cold and temperate wetlands called bogs, typical of northern Canada. *Sphagnum* bogs are more acid than normal fresh-

MAIN IDEA

The bryophytes are the simplest of the true plants. Their most unique characteristic is their lack of a vascular system, which prevents them from growing tall.

Various species of *Sphagnum* moss can be found growing in bogs. The dead plants may become compressed at the bottom of the bog as peat.





While most mosses grow in moist environments (top right), some species are able to grow in relatively dry areas (top left).

MAIN IDEA

The mosses are by far the largest group of bryophytes. They are small plants that grow mostly in clumps. Several other kinds of plants are erroneously called mosses.

SCIENCE BACKGROUND

“Reindeer moss” is actually a number of different lichens, which are about the only producers that thrive in the tundra.

water, and decomposer micro-organisms do not thrive in them. Therefore, as the mosses die they often build up and do not decompose. Over the years, layers of dead sphagnum build up and become compressed, forming a substance called **peat** (pēt). Peat is used as a bedding, or mulch, in vegetable and flower gardens. It is sometimes burned as a fuel. Many old bogs have been cleared of sphagnum and are now used to grow cranberries.

19–3 The mosses The mosses (class Musci) are by far the largest group of bryophytes. Most of them grow in clumps on moist soil, but some are aquatic, and some even live in deserts. In rain forests, where moisture and plant life are abundant, mosses also grow as **epiphytes** (ep’ə fitz). Epiphytes are plants that grow on other plants, such as trees, but are nonparasitic. They do not take nourishment from the plants they are growing on.

Unfortunately many other kinds of plants are incorrectly called mosses. “Reindeer mosses,” which are common in the northern tundra, are lichens (combinations of fungi and algae). “Spanish moss,” which is an epiphyte that hangs from trees in the South, is a vascular seed plant. Often *moss* is used incorrectly as a name for numerous species of algae that grow on the surface of ponds and other bodies of water.



19-4 Alternation of generations In their life cycle, Bryophytes have two generations that alternate with each other—a pattern called **alternation of generations**. One generation, called the **gametophyte** (gə mē'tə fīt), produces the sperm and eggs, or gametes. The gametophyte alternates with the other generation, the **sporophyte** (spôr'ə fīt). The sporophyte produces spores.

19-5 The moss gametophyte The moss gametophyte develops after a spore germinates and starts growing. The spore is **haploid** (hap'loid), which means that it has only one set of chromosomes ($1N$). Therefore the cells of the gametophyte are all $1N$.

After the spore germinates, the first growth looks like a thread of green algae. It is called a **protonema** (prō tə nē'mə). The name means “first thread.” As the protonema continues to develop, it sends out **rhizoids** (rī'zoidz). The rhizoids are threadlike extensions that grow into the soil. They anchor the plant and may absorb water and minerals.

The protonema also grows “buds” that develop into the main body of the gametophyte. The gametophyte consists of a short stem with green, pointed leaves growing in a spiral around it. However, they are not true leaves or stems because they lack vascular tissue.

Bryophytes, such as these mosses, can often establish themselves on rocks and other places where more complex plants cannot grow.

MAIN IDEA

Bryophytes reproduce by a pattern called alternation of generations, which has a gametophyte generation alternating with a sporophyte generation.

MAIN IDEA

Moss gametophytes develop from $1N$ spores and when mature produce antheridia and archegonia.

SCIENCE BACKGROUND

One of the most difficult jobs in biology teaching is to convince students that the gametophyte and the sporophyte—particularly those of the mosses—are actually separate plants. It sometimes helps to have moss gametophytes and sporophytes in class so that the students can actually separate the two, and then discuss the relative dependency of the sporophyte on the gametophyte.

Spanish moss can be seen growing on the trees in this photograph. Although the moss plants grow on the trees, they are not parasitic on them.



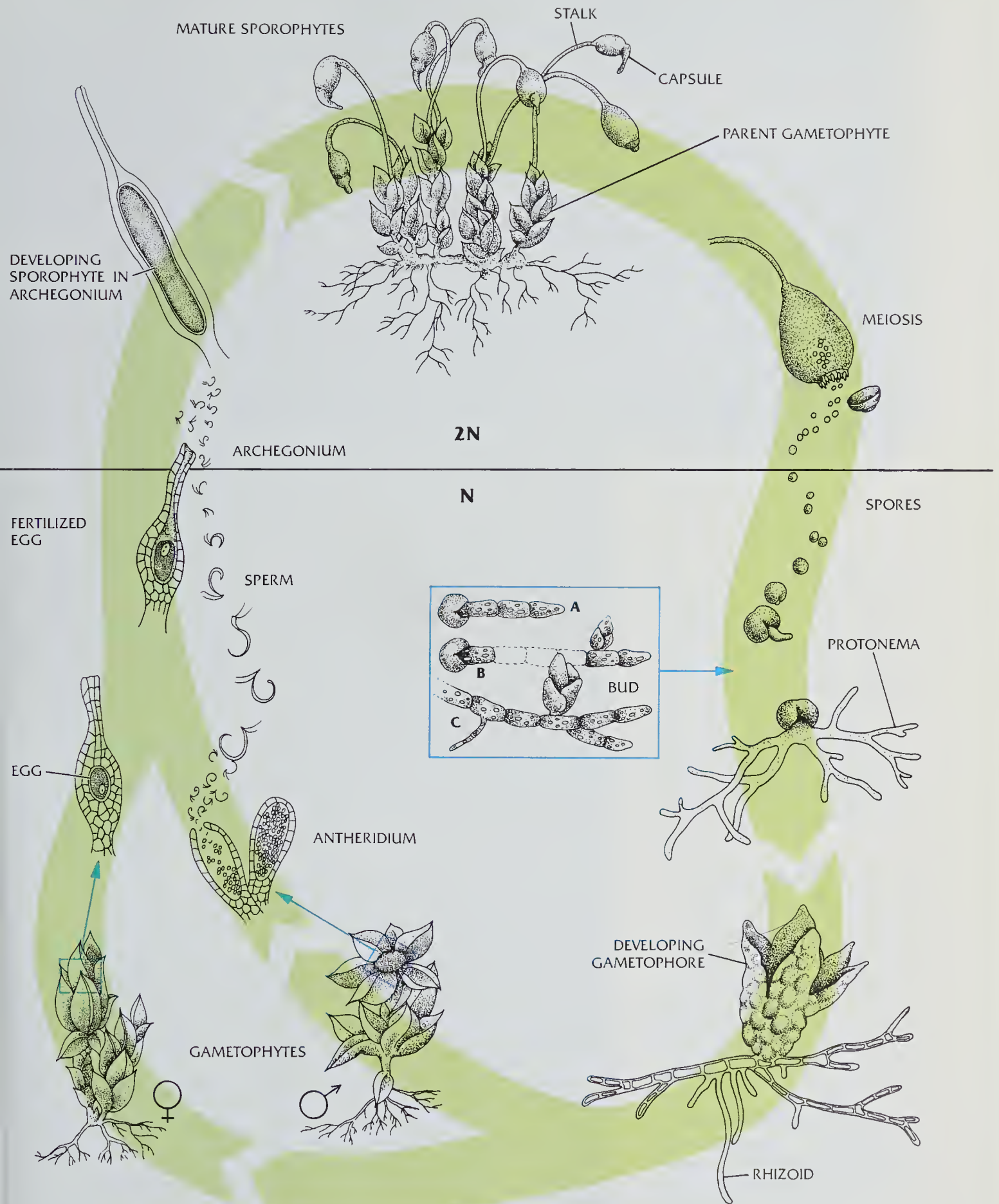
SCIENCE BACKGROUND

The leaves of the gametophyte are often one cell thick except for a midrib that is often present. The leaves that dry out and absorb water lack cutin, which is a waxy coating found on the leaves of higher plants. The drying out of the leaves enables them to survive freezing because ice crystals are not formed in the cells. Generally those mosses with cutin have some water-conducting tissue in their stem; those without cutin lack such tissue and depend heavily on the absorption of water directly into the leaves.

The leaves of many moss gametophytes have a special ability to withstand drying and then to absorb water rapidly. For example, certain species in arid regions can shrivel up, turn brown, and look as if they were dead. Later, when just a few drops of water fall on them, they expand and turn a brilliant green color in a short time.

When the gametophyte plants mature, they develop sex organs at the top of the plants. The male sex organ, the **antheridium** (an thə rid'ē əm), produces sperm cells. The female sex organ, the **archegonium** (är kə gō'nē əm), produces an egg. Fertilization occurs when the plants are wet and the sperm can swim to the egg. The sperm are believed to be guided by chemicals released by the archegonium.

FIGURE 19–1 Alternation of generation in a typical moss plant is shown in this illustration.





The slender brownish stalks, each topped by a brownish capsule, are moss sporophytes. Each is attached to a gametophyte by the stalk.

MAIN IDEA

Moss sporophytes develop from a fertilized egg ($2N$) into slender stalks that grow from the top of gametophytes. The sporophyte produces spores that are stored in a capsule at the top of the stalk until conditions are favorable for dispersal.

SCIENCE BACKGROUND

As the sporophyte starts to develop, the archegonium expands and becomes the *calyptra*, which is a covering over the capsule. The correct name for the sporophyte stalk is *seta*. The tip of the capsule is covered by a lid, or *operculum*. When it falls off, it exposes one or more rows of *peristome teeth*. When conditions are favorable, the teeth bend and unbend, acting like little catapults in scattering the spores.

19–6 The sporophyte After fertilization the egg divides and eventually develops into a completely new plant, the sporophyte. However, the sporophyte is **diploid**, having received two sets of chromosomes ($2N$)—one each from the sperm and the egg.

The moss sporophyte does not look like the gametophyte. It is a slender stalk with a foot that remains attached to the top of the gametophyte. At the top of the stalk is a capsule in which the spores are produced. The stalk usually has a central strand of cells that may carry food and water upward from the gametophyte. However, the sporophyte also has chlorophyll and carries on photosynthesis. Botanists (plant biologists) are not sure how dependent the sporophytes are upon the gametophytes for their nourishment.

The spores, which are produced by meiosis inside the sporophyte capsule, are haploid cells. They are released, usually with force, when conditions are most favorable for their dispersal. Often they are released in dry seasons, when they can be scattered by wind currents.

The spore may germinate as soon as it is released. If it does, it will develop into a protonema, then into a new gametophyte plant. However, the spore may remain dormant for many years before it germinates. Spores that were stored in a laboratory for 55 years were still capable of developing into healthy gametophytes.

19-7 Other methods of reproduction Mosses are also capable of reproducing by **fragmentation**, which is a special form of asexual reproduction. By this method the gametophyte branches and rebranches. As this branching occurs, older parts of the gametophyte die causing parts of the plant to separate.

Another asexual method is by **gemmae** (jem'ē). These are small, flat bodies that grow in little cups on the leaves, stems, or rhizoids of the gametophyte. The gemmae, when released, can develop into new gametophytes.

19-8 The liverworts Most liverworts (class Hepaticae) grow flat on moist ground, logs, and trees. Many are made up of leaflike structures that were thought to look like liver—hence their name, which means “liver herb.”

MAIN IDEA

Mosses also reproduce asexually by fragmentation and gemmae, which are small, flat bodies that grow in cups on leaves, stems, or rhizoids.

MAIN IDEA

There are two types of liverworts, which are flat-growing plants found on moist ground, logs, and trees. The leafy form is most common in the tropics. The thallose form is the one we are likely to observe in temperate regions.



Marchantia, shown at left, is a liverwort that has the thallose body form. In liverworts the gametophyte is the conspicuous generation.



The umbrella-shaped structures in the photograph at left are the female sex organs of Marchantia. The eggs are produced in these structures.

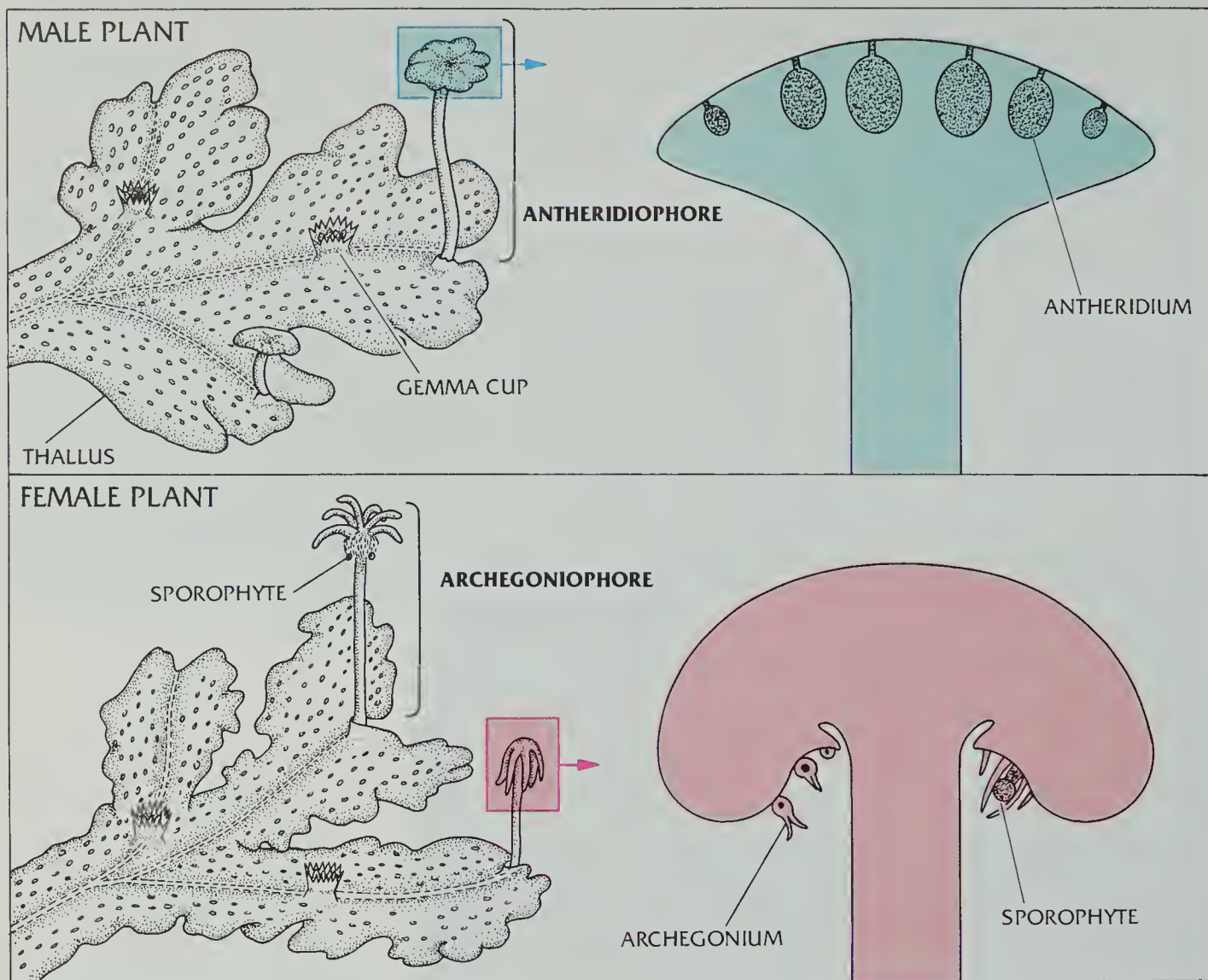


FIGURE 19-2 In *Marchantia* both the male and female sex organs grow from the dorsal surface of the gametophyte plant.

SCIENCE BACKGROUND

Liverworts were apparently named in the ninth century when the "Doctrine of Signatures" held that one could determine the usefulness of a plant by its appearance. The liverwort was believed to be useful in treating diseases of the liver.

MAIN IDEA

Marchantia, a thallose form, is one of the most common liverworts. It reproduces by alternation of generations and also by fragmentation and gemmae.

There are two types of liverworts. One type has a **leafy form**, with many leaflike structures branching off a stem. More than two thirds of all liverworts are of this type. Most live in tropical rain forests and many are epiphytes.

The other type of liverwort has the **thallose form**, which has a flat body without a stem. Most of the liverworts found in temperate regions are of the thallose form.

19-9 *Marchantia* One of the most common groups of liverworts has the thallose form and is called *Marchantia*. The gametophyte of *Marchantia* is the main plant body. It is often one of the first pioneer plants to be found growing after a forest fire.

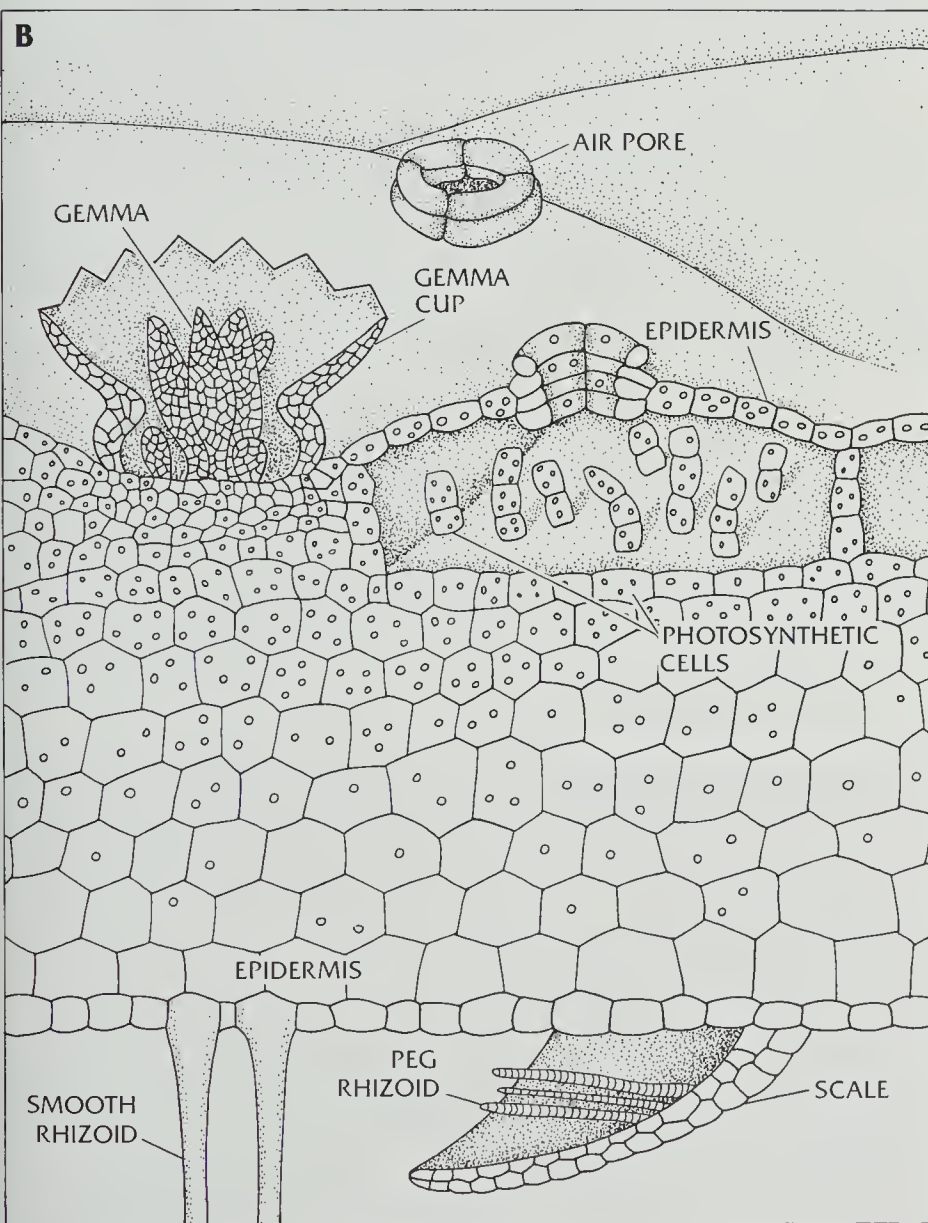
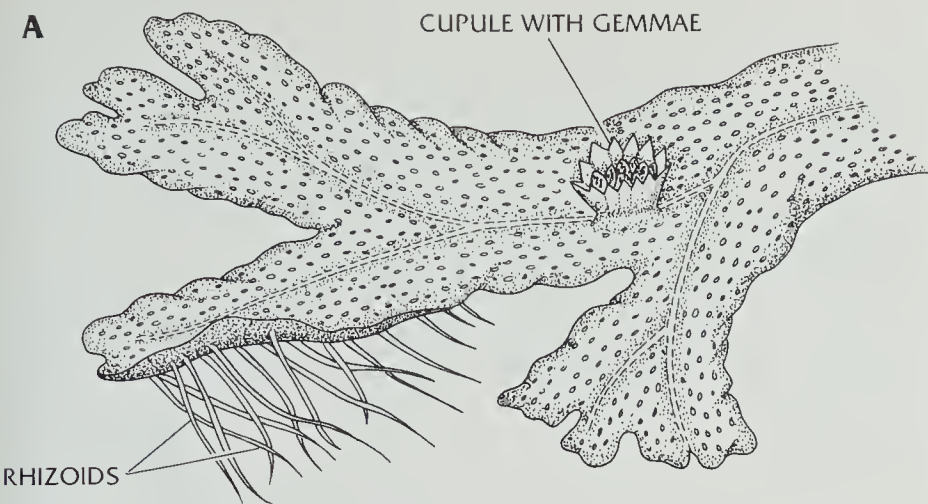


FIGURE 19-3 The detailed structure of a *Marchantia* gametophyte is shown in this illustration. *Marchantia* can reproduce asexually with gemmae.

SCIENCE TERMS

vascular system
pioneer plants
peat
epiphytes
alternation of generations
gametophyte
sporophyte
haploid
protonema
rhizoids
antheridium
archegonium
diploid
fragmentation
gemmae
leafy form
thallose form

SCIENCE BACKGROUND

During seasons with short days *Marchantia* forms gemmae cups and reproduces asexually. On days of 12 h or more the sex organs develop and sexual reproduction occurs. Only a film of water is necessary for the sperm to reach the archegonium as long as the neck of the archegonium is immersed.

ANSWERS TO CHECK YOUR FACTS

1. A system for transporting material through the plant. Plants without a vascular system cannot grow tall.
2. Most are in tropical or semi-tropical forests. Many survive in moist northern climates.
3. A plant that can establish



FIGURE 19-4

The sporophyte of *Marchantia* remains attached to the archegonium.

itself where no plants are growing.

4. Sphagnum dies in a moist environment that is too acidic for decomposer microorganisms. The compressed Sphagnum is peat.

5. Plants that grow on other plants but are not parasitic since they do not take nourishment from the plants.

6. A protonema.

7. Extensions that grow into the soil. They act as roots by anchoring the plant. They may absorb water and minerals.

8. Gametophyte and sporophyte. The gametophyte produces gametes; the sporophyte produces spores.

9. A sporophyte. It produces spores.

The thallose body of *Marchantia* is thick and has diamond-shaped areas on its dorsal surface. Also on the dorsal surface are numerous pores, which are openings into photosynthetic chambers where gas exchanges occur. On the underside of the *Marchantia* body there are rhizoids and scales that help anchor the plant. They also absorb moisture and nutrients.

Like the mosses, the *Marchantia* life cycle is an alternation of generations. The sex organs grow from the dorsal surface of the gametophyte. The antheridium is a round, dish-shaped body on a stalk. Drops of water falling on the antheridium help disperse the sperm by splashing them over the plant. The archegonium, where the eggs are produced, is an umbrella-shaped organ. It is also on a stalk, which grows after fertilization occurs.

The sporophyte of *Marchantia* is very small. It grows out of the archegonium and has a foot, a short stalk, and a capsule somewhat like the moss sporophyte.

Marchantia also reproduces asexually by fragmentation and by gemmae. The gemmae are produced in cups on the surface of the gametophyte. Falling drops of rain cause them to splash out and be washed to places where they can develop into new gametophytes.

19-10 The hornworts A small group of bryophytes, found mostly in the warmer regions of the world, are called hornworts (class Anthocerotae). They resemble the liverworts but have tall, slender spore capsules that split lengthwise and resemble animal horns.

The hornworts have the same basic reproductive pattern as the mosses and liverworts. Some will reproduce asexually by gemmae.

CHECK YOUR FACTS

1. What is a vascular system? How does this relate to plant height?
2. Where are bryophytes found?
3. What is a pioneer plant?
4. How is peat formed?
5. What are epiphytes? Are they parasitic? Explain.
6. What do we call the first growth of the moss gametophyte?
7. What are rhizoids? What are their functions?
8. What are the two alternating generations in the life cycles of bryophytes? What are the reproductive products of each generation?
9. What is the slender stalk that appears on top of the moss gametophyte? What is its function?

SUMMARY

The bryophytes are the simplest of the true plants. They include the mosses, liverworts, and hornworts. They are different from other true plants because they lack a vascular system. This limits their height; therefore, most are small plants. Bryophytes are usually found in a moist forest habitat. They are often pioneer plants that become established in barren areas until other plants take over. The typical life cycle of bryophytes follows a pattern called alternation of generations. The gametophyte generation alternates with the sporophyte generation.

REVIEW QUESTIONS

1. Trace the life cycle of a moss, beginning with a germinating spore.
2. How does a spore differ from a gamete in forming new plants?
3. What parts of the moss have diploid cells?
4. How does fertilization occur in bryophytes?
5. What are two types of liverworts? Where are the two types of liverworts found?
6. Where are the sex organs located in *Marchantia*?
7. What are gemmae?
8. How would you distinguish between a hornwort and a liverwort?
9. Is it likely that a liverwort could act as both a pioneer plant and an epiphyte at the same time? Can you explain why this is true?
10. With a few exceptions, what characteristic is common to all the places where the bryophytes are found?

ANALYSIS AND APPLICATION

1. A forest fire burns several days over hundreds of acres, destroying all living organisms in its path. Within a few weeks, however, we find *Marchantia* growing in the area. Some *Marchantia* are miles from the nearest unharmed forest. How would you explain this rapid recovery of the growth of *Marchantia*?
2. It is commonly believed that moss grows on the north side of trees. While this is not always true, can you explain why this statement is often true?
3. Most bryophytes can only survive in very moist areas. Can you give some reasons for this?
4. Of what value are pioneer plants? What do they provide for the plants that follow?

ANSWERS TO REVIEW QUESTIONS

1. See Figure 19-1.
2. A spore can germinate to form a gametophyte. A gamete, however, must be united with another gamete to form a fertilized egg.
3. The sporophyte.
4. The sperm swims through water to the egg.
5. The leafy form, usually found in tropical rain forests, and the thallose form, more common in temperate regions.
6. On a stalk on the dorsal surface of the gametophyte.
7. Gemmae are small, flat bodies that grow in little cups on the surface of a gametophyte. They can develop into new plants when released.
8. A hornwort has tall, slender spore capsules.
9. No. An epiphyte grows on another plant. A pioneer plant would not have host plants to live on.
10. Abundant moisture.

ANSWERS TO ANALYSIS AND APPLICATION

1. The dormant spores of *Marchantia* survived.
2. In the Northern Hemisphere, the north side of a tree, receiving less direct sunlight, retains enough moisture to support the moss.
3. They have no vascular system to transport water from a source. Sexual reproduction is dependent on the presence of water. These plants are not well equipped to store water.
4. They grow where other plants cannot survive. By doing this, a process is started that can eventually enable many organisms to inhabit the area. The important thing that pioneer plants provide for other plants is suitable soil.

20 *Seedless Vascular*



Plants

OBJECTIVES

- To appreciate the kinds of plants that once dominated our landscape
- To identify horsetails
- To identify *Lycopodium* and *Selaginella*
- To understand the relative importance of ferns
- To describe the fern life cycle
- To discuss the ecological role of ferns

20–1 Division Tracheophyta The second major division within the plant kingdom includes the vascular plants of the division Tracheophyta. These plants all have a vascular system for conducting water and food through the stems, roots, and leaves.

There are five subdivisions of the division Tracheophyta, but only four of them have members that are still alive. One subdivision is extinct.

Three of the subdivisions with members that are still living do not produce seeds. They will be discussed in this chapter. The fourth group, the seed plants, will be discussed in Chapter 22.

20–2 The horsetails One subdivision (Sphenopsida) has only 20 living species. These are members of the genus *Equisetum* and are commonly called horsetails. About 300 million years ago, the relatives of the horsetails were major plants that dominated the landscape. Some were trees 15 m tall. Numerous fossils of those ancient plants have been found, and the horsetails of today are just like many that lived 300 million years ago. The horsetails are truly “living fossils.”

Most horsetails grow in moist locations and are easy to recognize. They are usually less than a metre tall, and most have a green stem that looks jointed. However, the stem is not jointed. A closer view of what looks like a joint reveals a circle of tiny leaves. Some species also have branches that extend out from between the leaves. Those with branches probably reminded someone of a horse’s bushy tail and hence the common name.

MAIN IDEA

Of the four living subdivisions of the division Tracheophyta, which are vascular plants, three do not produce seeds. These are discussed in this chapter.

Horsetails were once the dominant form of plant life on earth.



MAIN IDEA

The horsetails dominated the ancient landscape, but only a few survive as “living fossils.” Most grow in moist locations, appear to have jointed stems, have silica in their epidermis, and produce spores from strobili that grow at the top of the plant. The gametophytes are small and seldom observed.

The horsetails have stems that are mostly hollow. The water- and food-conducting tissues are located around the outer part of the stem. The tissue on the outside of the stem, the **epidermis** (ep ə dēr'mis), has cells with silica in their walls. This gives the plant a rough touch when it is crushed and is responsible for another common name for these plants. Early pioneers in America called them scouring rushes and used them to scour pots and pans.

The horsetails that we see are members of the sporophyte generation. Spores are produced in cones, or **strobili** (strob'ə lī) (sing. *strobilus*), that grow at the top of the plant. These spores, when released, germinate and develop into a very small gametophyte. Most gametophytes are less than 1 cm across and many are much smaller. The gametophytes usually produce either **antheridia** (an thə rid'ē ə), male sex organs, or **archegonia** (är kə gō'nē ə), female sex organs, but some produce both. Sperm, when released from the antheridia, have to swim through water to fertilize the egg. The fertilized egg then develops into the sporophyte that we know as the horsetail.

MAIN IDEA

The lycopods, or club mosses, are also “living fossils,” and the plants that we observe are the sporophytes.

A strobilus is visible at the top of *Lycopodium* (left). *Selaginella*, a spike moss, also produces spores within strobili.

20–3 The lycopods Another group of “living fossils” is the lycopods (subdivision Lycopsidea). They too dominated the landscape about 300 million years ago. Now about 800 species survive, most of which live in tropical habitats. Many have strobili and look like moss gametophytes, hence the common name of club moss for many species.





SCIENCE BACKGROUND

The unique feature of lycopods is their lateral sporangia. Most have a single-veined leaf. Years ago lycopodium spores were sold in pharmacies as "lycopodium powder," which was used for dusting babies to prevent diaper rash. The spores are said to be so water-repellent that hands covered with the spore powder remain dry while submerged.

The fronds of ferns are common sights in most forested areas. Ferns are the most successful group of seedless vascular plants.

SCIENCE BACKGROUND

Equisetum is the sole surviving genus of a group that dates back to the Paleozoic Era. It is found everywhere but in Australia and Antarctica. There is one giant species, *Equisetum giganteum*, that grows up to 6 m tall in tropical areas, but it is supported by other vegetation.

The stem of *Equisetum* is the main photosynthetic structure. However, some species send up two stems—one nongreen but with cones; the other, green but sterile. North American Indians used the young nongreen shoots as food and considered them a delicacy.

MAIN IDEA

The ferns are by far the largest group of seedless vascular plants. The part of the fern that we observe is the frond, which is the leaf of the sporophyte that grows from rhizomes. The spores are usually produced in clusters of sporangia on the underside of the fronds.

Lycopodium is a common lycopod that survives in the cold forests of North America. Its leaves remain green throughout the year. *Lycopodium* is a creeping plant that grows low across the ground. It is often called ground pine and for many years was used for Christmas decoration. Now, because it is becoming rare in many areas, some states have protected these plants by making it illegal to collect them.

Another common lycopod is *Selaginella*, which has some species that live in temperate regions. Most are small plants and all have strobili that produce spores.

All the lycopods that we observe as mature plants are the sporophyte generation. The gametophytes of *Lycopodium* are very small and some grow underground and are never observed. The gametophytes of *Selaginella* and its relatives produce both male and female gametophytes, which are merely clusters of cells on the sporophyte.

20-4 The ferns The largest group of seedless vascular plants is the ferns (subdivision Pteropsida). The ferns were present in the ancient landscape but were not as dominant as the other plants we have discussed. But today ferns are very successful plants. About 65 percent of the species live in tropical habitats. Some, however, are very hardy and can survive in desert and arctic habitats.

The ferns are important pioneer plants. In the north woods of America, the bracken fern is the most common pioneer plant. It is the first to invade disturbed areas, such as places where power lines or ski trails are built.



Sori, clusters of sporangia, can be seen on the frond at left. The spores develop into a prothallus (right), the fern gametophyte.

SCIENCE TERMS

epidermis
strobili
antheridia
archegonia
fronds
rhizomes
sporangia
sori
prothallus

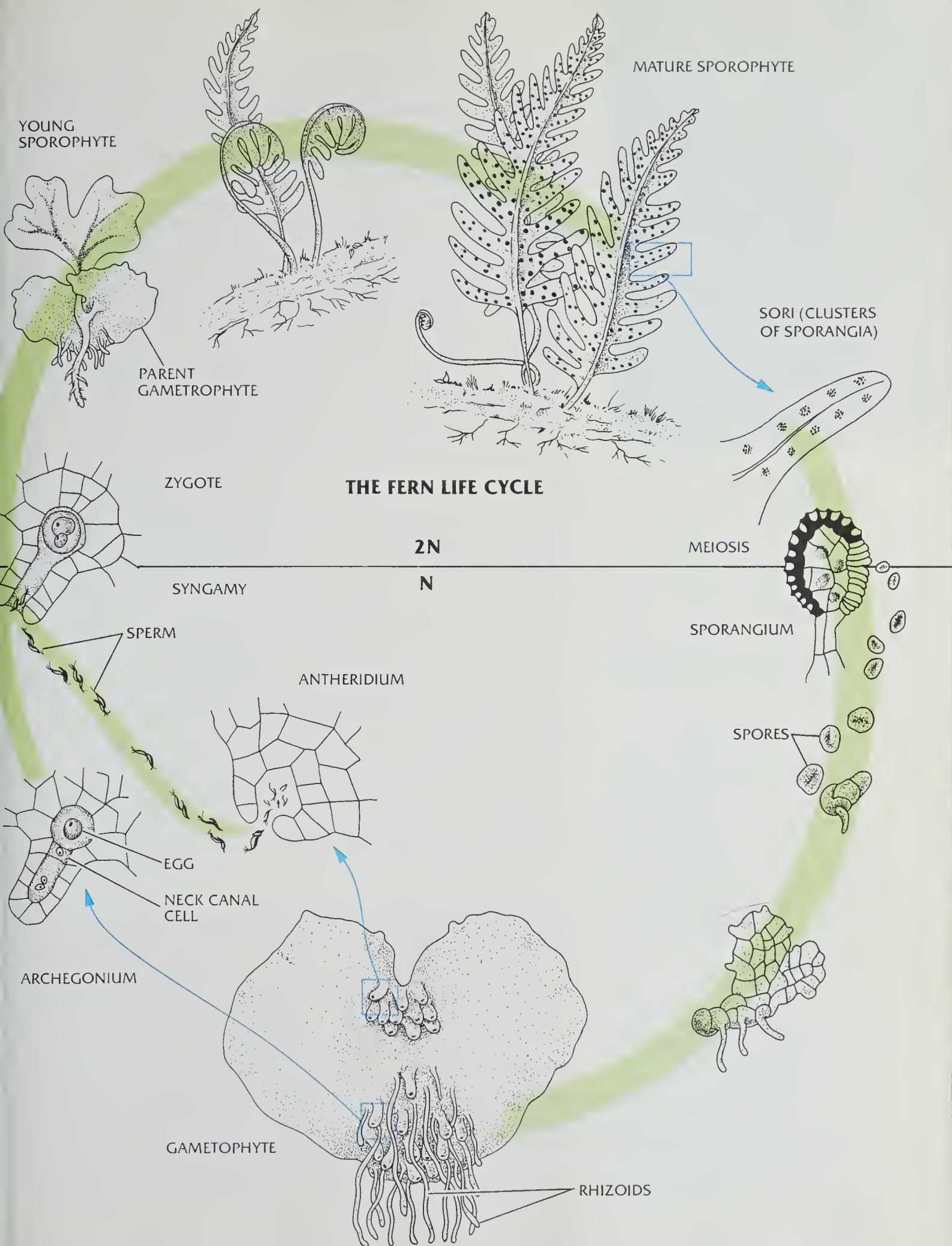
Most ferns that we see are actually fern leaves, or **fronds** (fronds). The fronds grow from underground stems called **rhizomes** (rī'zōmz). the bracken fern, one of the most common ferns throughout the world, is an example of such a fern. The rhizome sends up a number of fronds and also produces roots that absorb nutrients. The roots, rhizome, and fronds make up the sporophyte generation of the fern.

Fern spores are usually produced in clusters of **sporangia** (spə ran'jē ə), or spore capsules, on the underside of the frond. These clusters of sporangia, called **sori** (sôr'ē), are easily observed. When the spores are ripe, the sporangia dry up and split open, causing the spores to be thrown away from the plant. Most spores are extremely light and are carried great distances by the wind. Charles Darwin, on his famous round-the-world trip, found fern spores in air samples taken hundreds of kilometres from land.

MAIN IDEA

The fern gametophyte is very small, is seldom observed, and may live independently from any known sporophyte.

20–5 The fern gametophyte When a fern spore germinates, it develops into the fern gametophyte, which is called a **prothallus** (prō thal'əs). The prothallus is usually less than 1 cm wide and is seldom observed. The typical prothallus is green, carries on photosynthesis, and is independent of the sporophyte. The antheridia and archegonia are on the ventral side of the prothallus, and the sperm must swim through water to reach the egg.





The developing frond of the fern sporophyte is called a fiddlehead.

ANSWERS TO CHECK YOUR FACTS

1. Tracheophytes have a vascular system; bryophytes don't.
2. Less than 1 m high with circles of tiny leaves.
3. While the plants have not changed much, the number of surviving species has declined.
4. The outermost tissue. The epidermal cells contain silica.
5. Spore-producing cones at the top of some tracheophytes.
6. Members of subdivision Lycopsidea. Tropical habitats
7. *Lycopodium*; *Selaginella*.

ANSWERS TO REVIEW QUESTIONS

1. Today ferns are much more abundant than horsetails. Long ago the horsetails were more plentiful than ferns.
2. An organism that has changed very little over a long period of time. Horsetails and lycopods are examples.
3. It is the most common pio-

When the egg is fertilized, it develops into a new sporophyte. However, some gametophytes can reproduce asexually by gemmae (small disks of cells). There are even some fern gametophytes that live independently, with no known sporophyte.

20-6 The developing sporophyte The developing sporophyte frond has an unusual appearance. The cells on the lower surface of the developing frond grow faster than those on the dorsal surface. This causes the developing frond to coil, producing what is called a "fiddlehead."

Most ferns have little economic value as food for people or livestock. But the young fiddleheads of the ostrich fern, found in eastern North America, are edible.

Some sporophytes have stems that grow above the ground. One example is the tree fern, which grows in many tropical forests. Another example is a climbing fern (*Gleichenia*), which has fronds that continue to grow as long as they are alive. Most fronds stop growing after they reach a certain length. These climbing ferns may develop fronds up to 50 m long. Sometimes they are serious pests in tropical gardens and orchards.

The bracken fern is a serious pest in many parts of the world. In Great Britain and New Zealand it crowds into grazing lands and competes with the native grasses. In New Zealand, ranchers and farmers struggled for many years to eliminate these ferns from their lands. They tried to dig out the rhizomes but found that by breaking the rhizomes they only caused the ferns to multiply. They tried overgrazing the ferns with sheep, but that made the sheep ill. Finally they learned that by cutting the fronds back repeatedly the food reserves in the rhizomes were eventually used up, causing the ferns to die.

CHECK YOUR FACTS

1. Name one difference between the tracheophytes and the bryophytes.
2. Describe the appearance of a horsetail.
3. What changes have occurred in horsetails in the past 300 million years?
4. What is epidermis? Why is it rough in horsetails?
5. What are strobili?
6. What are lycopods? Where are they found?
7. What are two common lycopods found in temperate regions?

SUMMARY

Three subdivisions of division Tracheophyta that do not produce seeds are discussed in this chapter. The horsetails, dominant in the ancient landscape, now number only 20 living species. Most grow in moist places and are less than a meter high. The stem appears to be jointed because of circles of tiny leaves and may also have branches extending out from these “joints.” Silica in the epidermis makes the stem feel rough. Spores are produced in strobili on top of the plant.

The lycopods were also once dominant plants. They still include about 800 living species, most of which are tropical plants. *Lycopodium* and *Selaginella* are two common lycopods that live in temperate regions.

The ferns are the largest group of seedless vascular plants. Many ferns, such as the bracken fern, are important pioneer plants. The visible part of the fern is the fronds, or leaves, of the sporophyte.

REVIEW QUESTIONS

1. Compare the abundance of ferns with that of horsetails—both now and 300 million years ago.
2. What is a “living fossil”? Give an example.
3. What is significant about the bracken fern?
4. What are fronds? From what do they grow?
5. What are sori? Where are they located?
6. How do the gametophytes of ferns differ from the moss gametophytes?
7. Describe how a fern reproduces.
8. Describe a way in which the bracken fern is useful. How is it a pest?
9. How are fern spores distributed? What is the range of this distribution?
10. What causes a “fiddlehead”?
11. Using common names, list the subdivisions of division Tracheophyta.

ANALYSIS AND APPLICATION

1. Seedless plants dominated the landscape 300 million years ago. Today seed plants, such as trees and grasses, are the major plants. This is partly because the climate of the earth has changed. How would you compare the present climate with that of 300 million years ago? Explain.
2. What advantage do plants that reproduce by seeds have over the seedless vascular plants?

neer plant in many areas.

4. Fronds are fern leaves. They grow from rhizomes.

5. Sori are clusters of sporangia. They are usually on the underside of the frond.

6. While moss gametophytes are the main body of the moss plant, the gametophytes of ferns are so small they are seldom seen.

7. The germinating spore produces the prothallus. The sex organs develop on the ventral side of the prothallus. When the egg is fertilized, it develops into a sporophyte. The sporophyte produces and releases spores.

8. It is a pioneer plant that helps reclaim disturbed areas. It can also be a pest because it competes with grasses that are used for grazing.

9. They are carried by wind. The range is very large—up to several hundred kilometres.

10. The cells on the underside of a developing frond grow faster than those on the dorsal surface. This causes the frond to curl.

11. The horsetails, the lycopods, the ferns, the seed plants, and one extinct group.

ANSWERS TO ANALYSIS AND APPLICATION

1. One obvious difference between the seedless plants and the seed plants is the former's greater need of water. It is reasonable to assume that the decline of the seedless plants was partly caused by drier conditions for which they were not adapted. Thus the present climate is drier than in earlier periods.

2. They have a simple life cycle that does not involve two separate plants, a gametophyte and a sporophyte.

Investigations 33–34
from *Laboratory Investigations*
in *Biology* can be done with this
chapter.

21 *The Seed*



Plants

OBJECTIVES

- To understand that the seed plants have replaced the nonseed plants
- To appreciate the nature and importance of the conifers
- To understand the unusually long life cycle of conifers and the mechanism of their reproduction
- To explain the reasons for the dominance of the angiosperms
- To know the parts of a typical flower and how they function
- To describe the ways that pollination occurs
- To understand the unique double fertilization that results in an endosperm and a zygote
- To understand the biological definition of a fruit
- To know the difference between monocot and dicot plants

Introduction

21-1 The dominant plants We have discussed plants that dominated the landscape millions of years ago. These were plants such as the horsetails, lycopods, and ferns. But the dominant plants of today—the plants that give our planet its basic green color—are the seed plants. We shall discuss the seed plants in this chapter.

Why are the seed plants dominant today? To answer that question we must look at the selective advantages that seed plants have over the other plants we have discussed. First, seed plants have an advantage in the type of gametophyte they produce. Seed plants produce extremely small gametophytes that are hardy. The gametophyte is completely dependent upon the sporophyte that produces it. The gametophyte is like a very small parasite that develops on the sporophyte, which *is* the seed plant. The small gametophyte gives the seed plant an advantage over the nonseed plant. The gametophyte of the nonseed plant has to find a favorable place for development. It also has to provide its own water and nutrients and to survive long enough to produce gametes and a sporophyte embryo. The seed plant gametophyte has none of these problems.

The second advantage of seed plants is that water is not required for fertilization. You will recall that the sperm of nonseed plants always have to swim through water to reach the egg. The sperm of seed plants never have to swim through water. Thus they are more independent and better adapted for survival in dry habitats. The fact that water is not required for fertilization helps to explain the success of the seed plants.

MAIN IDEA

The seed plants have two advantages: (1) The gametophyte is self-contained and thus does not have to compete for space, water, and nutrients or run the risk of independent survival. (2) Water is not necessary for fertilization to occur.

SCIENCE BACKGROUND

When studying the ferns, the students saw that the sporophyte was the dominant plant, while the gametophyte was small and inconspicuous. Now it should be emphasized that the sporophyte of the seed plant *is the seed plant* and that the gametophyte is reduced to just a few cells that develop within the sporophyte's body. The sporophyte produces two different spores: the microspore that produces the male gametophyte and the megaspore that produces the female gametophyte.

MAIN IDEA

Another major reason for the success of seed plants is that the seed, which contains a dormant embryo and an endosperm, is surrounded by a tough protective testa.

SCIENCE TERMS

embryo
dormancy
endosperm
testa

SCIENCE BACKGROUND

Not all seeds survive for long periods of time. Orchid seeds live for only a few days.

21-2 The seed The seed itself also helps to explain the great success of the seed plants. A seed consists of three basic parts. One part is a small, partially developed plant called the **embryo**. The embryo is in a state called **dormancy**, in which life processes have slowed down or completely stopped.

The second part of a seed is a collection of stored food called the **endosperm**. The endosperm is used by the embryo before it goes into dormancy. It is also used after the embryo starts growing again. The endosperm nourishes the young plant until it is developed enough to begin manufacturing its own food by photosynthesis.

The third part of the seed is the seed coat, or **testa**. The testa is the outer layer of the seed and is normally very tough. It protects the enclosed embryo from physical damage and keeps it from drying out.

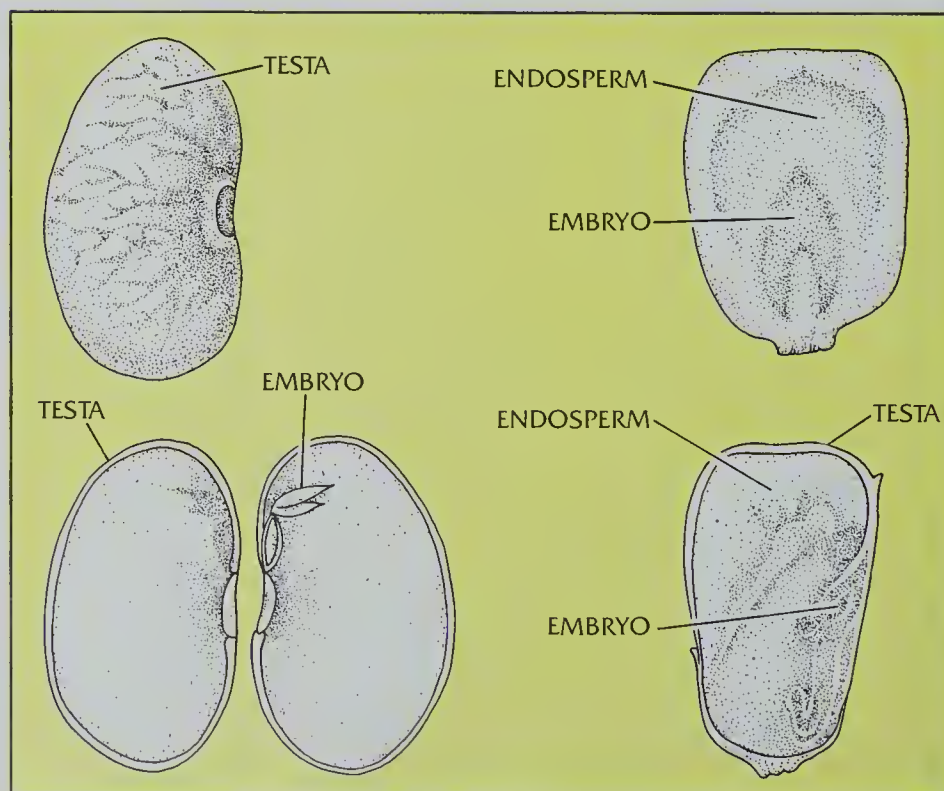
Most seeds have a great survival ability. This helps account for the success of the seed plants. Many seeds can survive such extreme conditions as freezing, high temperatures, and long periods of darkness. Most can survive for great lengths of time, until favorable conditions for plant growth are available. An extreme example was a 10 000 year-old arctic lupine seed, which was found buried in the Yukon. When botanists placed the seed in a favorable growth environment, it developed normally after having been dormant for all those years.

ANSWERS TO CHECK YOUR FACTS

1. Seed plants. They replaced the seedless plants.
2. They produce superior gametophytes and they do not require water for fertilization.
3. The seed plant gametophyte is dependent on the sporophyte. Unlike other gametophytes, the seed game-

FIGURE 21-1

A bean seed and a corn seed are shown in this illustration. Although they are from two different types of plants, both seeds contain the same basic parts.



CHECK YOUR FACTS

1. What type of plants dominate our planet today? What did they replace?
2. What are two selective advantages of seed plants over seedless plants?
3. How is the gametophyte of the seed plant superior to that of the seedless plant?
4. Why are seed plants better adapted to dry habitats than ferns or horsetails?
5. What do we mean by *dormancy*?
6. What is an embryo?
7. What is the function of the endosperm?
8. What is the testa? What two functions does it serve?
9. Why do seeds themselves help account for the success of seed plants?

tophyte does not have to struggle for water, food, and a place to develop.

4. Seed plants do not require water to fertilize their eggs as do the ferns and horsetails.

5. The state where life processes are slowed down or stopped.

6. That part of the seed that is the immature plant.

7. It is the food supply for the embryo in the seed.

8. The seed coat. It keeps the seed from drying out and protects it from physical damage.

9. They can survive over long periods in a variety of extreme conditions.

The Gymnosperms

21-3 Plants with naked seeds There are two basic groups of seed plants. One group, the **gymnosperms**, produces naked seeds, or seeds that are not enclosed within a specialized structure. The other group, the **angiosperms**, produces seeds that are enclosed within a specialized structure. This seed-containing structure is called a **fruit**, which is produced by a flower. The angiosperms, or flowering plants, will be discussed later in this chapter.

There are four classes of gymnosperms, but only one is of major importance. This one is the class that contains the **conifers**.

21-4 The conifers Included among the conifers (class Coniferae) are the pine, spruce, juniper, fir, hemlock, cypress, and larch. All these plants have woody stems. Most are trees, but a few are shrubs. Shrubs are bushy plants.

Most conifers have needlelike or scalelike leaves. Such leaves prevent water loss and help adapt conifers for living in dry climates.

Most conifer leaves are green throughout the year (evergreen) and live anywhere from 2 to 14 years. Exceptions are the larches and the bald cypresses, which shed their leaves once a year.

The conifers include the largest living organisms on the earth. There is a giant cypress near the town of Tula in Mexico that has a diameter of 15 m. The tallest trees are in

MAIN IDEA

The gymnosperms have one major class, the conifers.

Blue spruce is a long-lived conifer that is found throughout much of the western United States. It grows well at high elevations.





The Monterey cypress, shown above, is native to California. It is not closely related to the bald cypress of the eastern United States.



Bristlecone pines may live for over 5 000 years and are possibly the oldest living organisms on earth. They are found chiefly in Nevada.

California. They are the coastal redwoods, which grow up to 110 m tall.

The conifers also include the oldest living organisms on earth. The bristlecone pines of Nevada are up to 5 000 years old. Some botanists think the Tula cypress of Mexico may be even older.

The conifers are extremely important to our society. They provide about 85 percent of all the lumber that we use for building houses and furniture. Conifers are also used to produce the millions of tons of paper that we use each year, mostly in newspapers.

The native conifers were a great source of wealth for our new nation as it grew and spread westward. Now conifers are grown as “tree crops” in many regions, particularly in the South.

21–5 The pines The most numerous of the conifers belong to the family of pines. The leaves of pines are needlelike and are arranged in bundles of one to eight leaves.

All conifers produce two types of cones, and the pines produce both types on the same tree. One type, the **pollen cone**, produces pollen grains, which are immature male gametophytes. The other, the **seed cone**, is always larger than the pollen cone. The seed cone produces the female gametophyte and, eventually, the seeds. Sometimes the pollen cones are called male cones and the seed cones, female cones.

The male cone ripens in the spring and the pollen grains, or pollen, are released in great quantities. The pollen is very light and is spread for great distances by the wind.

The female cone begins to develop in the spring and produces a sticky secretion that catches the pollen in the air. Slowly the sticky material evaporates and draws the pollen inside. Then two processes occur slowly over a period of a year. First, the pollen grain **germinates**, or starts growing, and the gametophyte digests its way through the cone tissue. Second, the female gametophyte matures and produces an egg. This egg will eventually be fertilized by one sperm from the male gametophyte. But fertilization will not occur until the second spring—about one year after the pollen is released.

After fertilization the embryo continues to develop slowly, with the cells of the female gametophyte developing into the reserve food supply, or endosperm. After another year the seed cone usually begins to grow, which causes the cone scales to separate. By this time the seeds—complete with tough seed coat, embryo, and endosperm—are ready to be released. As the cone grows and the scales separate, the seeds fall out of the cone. The seed coat has a



Pines, such as the umbrella pine shown above, are the most numerous, successful, and economically important group of conifers.



MAIN IDEA (21–5)

The pines make up the largest group of conifers and are characterized by needlelike leaves arranged in bundles. Like all conifers, they produce male and female cones. Pollen from the male cone sticks to the female cone and is drawn inside where one year later a sperm from the pollen tube will fertilize an egg. Another year is required for seed development, but the seeds may not be released for many years.

The large seed cone in the center of the photograph at left is surrounded by many smaller pollen cones.

MAIN IDEA

Cycads, which are palmlike trees native to Florida, and Ginkgos, which have broad leaves and are suited to city living, are two other gymnosperms.



Although now found in North America, the Ginkgo is native to China. It is also known from fossils that date back several hundred million years.

winglike, thin extension that catches the wind. The seeds are usually spread over a large area.

The seed cones of some pines do not open for many years. When they do open, it is the result of heat. Usually this is the heat of a forest fire. This unusual adaptation causes the seeds to be released on ground where competition will not occur for the developing pines.

21-6 Cycads and Ginkgos Two other gymnosperms are found in North America, but they are “living fossils” with most of their relatives extinct. One group, the **cycads** (sī’kads) (class Cycadinae), are mostly tropical species. The cycads produce cones, but they have leaves like palm trees, which are flowering plants. There is only one cycad species that is native to America. It is a Florida species and was used by the Seminole Indians for making bread. A number of other cycad species have been introduced and grown as ornamental plants.

The other gymnosperm commonly found in North America is the **Ginkgo**, or maidenhair tree, which is the only survivor of a major class of gymnosperms. The Ginkgo has fan-shaped leaves. It is widely planted as a shade tree and is popular because it is hardy and resistant to insects and disease. It is also resistant to air pollution, which makes it well suited for growth in many cities.

SCIENCE TERMS

gymnosperms
angiosperms
fruit
conifers
pollen cone
seed cone
germinates
cycads
Ginkgo

Although they resemble palm trees, cycads are actually gymnosperms. These plants were abundant during the time of the dinosaurs.



CHECK YOUR FACTS

1. How are gymnosperms different from the other seed plants?
2. What is the most important class of gymnosperms? List some members of this class.
3. Describe the leaves of conifers. How are they adapted for living in dry climates?
4. How long do conifer leaves live?
5. Why are the conifers so important to people?
6. Compare the two types of cones found on pine trees.
7. Explain how pollen makes its way from the pollen cone to the inside of the seed cone.
8. During the year that precedes fertilization, what two processes occur in the female cone?
9. How are seeds released from pine cones? How long after fertilization does this usually occur?
10. How do some pines insure that their seeds will develop without heavy competition?

The Flowering Plants

21-7 The most successful plants The angiosperms, or flowering plants, started to dominate the landscape about 100 million years ago. Gradually they became the dominant plants in most of the temperate and tropical habitats, while the bryophytes and ferns declined in number. The conifers continued to survive mostly in dry, cold, and rocky habitats, where they mainly grow under natural conditions today. The flowering plants are now the most abundant plants on the earth.

Why are the flowering plants so successful? There are several reasons. They have deeper root systems. They have more efficient vascular systems. Their leaves are broader than the needlelike leaves of conifers, which gives them a much greater area for carrying on photosynthesis.

One of the most important reasons for the success of the flowering plants is their ability to reproduce faster than the other seed plants. The conifers, for example, often require two years to produce seeds. Some of the small flowering plants can grow to maturity and produce seeds within just a few days.

21-8 Structure of a flower Flowers are quite varied in structure, and we shall only describe an ideal or typical flower. Such a flower has four rings of flower parts, which are attached to the flower base, or **receptacle**. The

ANSWERS TO CHECK YOUR FACTS

1. Gymnosperms produce seeds that are not enclosed by a specialized structure.
2. The conifers (class *Coniferae*). Pine, spruce, fir, juniper, and hemlock.
3. They are needlelike or scale-like and prevent water loss.
4. With a few exceptions, most last from 2 to 14 years.
5. They provide our main source of wood for buildings, furniture, and paper.
6. Pollen cones are smaller and produce immature male gametophytes called pollen grains. Seed cones produce female gametophytes and eventually the seeds. Pollen cones ripen in the spring—seed cones begin to develop at that time.
7. The wind disperses the pollen from the male cone. It is then trapped by a sticky secretion on the female cone. As this substance evaporates, the pollen is drawn into the female cone.
8. The pollen grain germinates and the gametophyte digests its way through the cone tissue; an egg develops from the female gametophyte.
9. The seed cone grows, causing the scales to separate. The seeds can then fall out. This occurs at least a year after fertilization.
10. They release their seeds after a forest fire has destroyed much of the plant life.

MAIN IDEA

In a typical flower, the calyx and corolla produce odors or nectar, the stamens produce pollen, and the carpels produce the ovules.

FIGURE 21-2

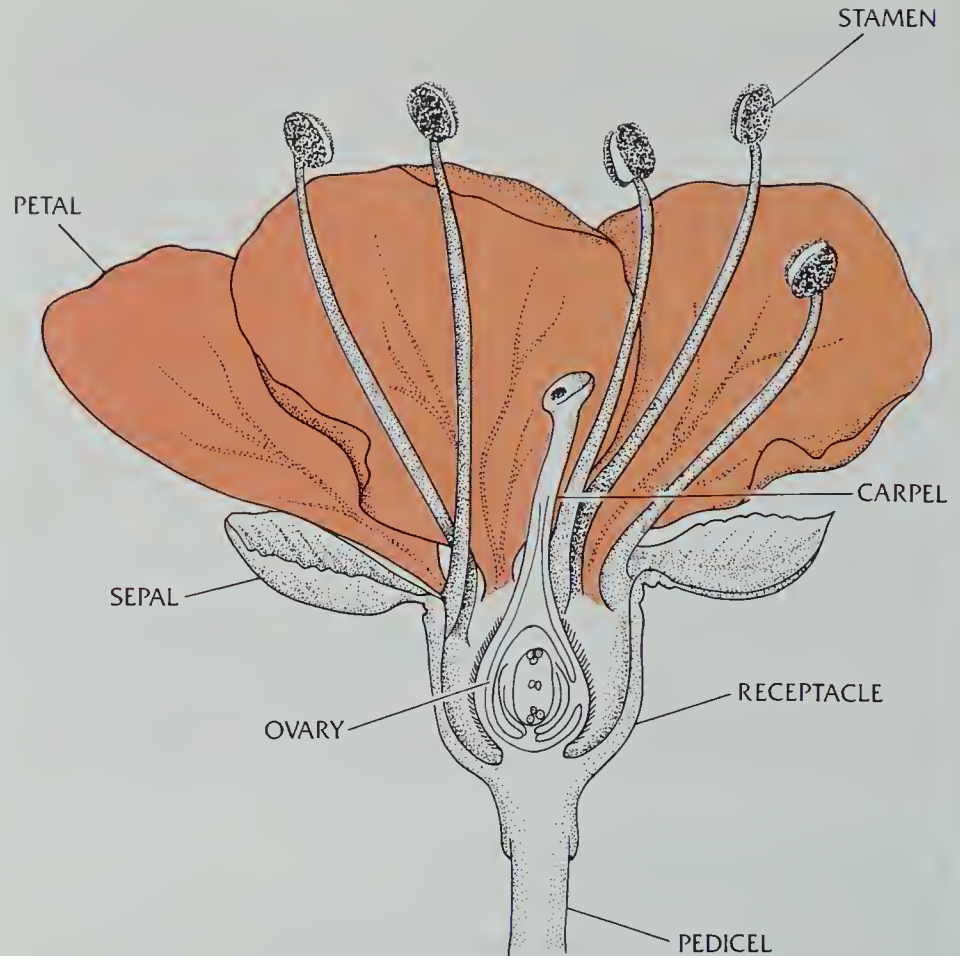
The structure of a typical flower is shown in this illustration.

SCIENCE BACKGROUND

Estimates of angiosperm species range from 235 000 to 300 000. Reasons for their success include a mechanism for dropping leaves in winter when they would be a liability, a deeper root system, a better supply of food in the seed, and seedlings that survive with less light. In addition the flowering plants have hundreds of adaptations that give them a competitive advantage in their environment—adaptations such as the narrow leaves of cacti that conserve water; stems that wind and cling to other plants; barbs, hooks, thorns, and tendrils that protect plants or enable them to cling in precarious locations.

SCIENCE BACKGROUND

Some sepals look like petals, for example, the tulip and many other members of the lily family. The only difference between the sepals and the petals is their location; the sepals are attached outside the petals.



outer ring of flower parts is the **calyx**. This is composed of individual parts called **sepals**. Often the sepals are green and leaflike in structure. The second ring of flower parts is the **corolla**, which is composed of individual parts called **petals**. The calyx and corolla have no direct reproductive function. However, they enclose and protect the main reproductive organs. Often the petals, and sometimes the sepals, are brightly colored. Also they may produce special odors and nectar, a solution with a high sugar content. The bright colors, special odors, and nectar all attract animals that pollinate the flowers.

The third ring of flower parts is composed of the male reproductive organs, the **stamens**. Their number varies in different flowers. Each stamen has two main parts. One part is the stalk, called the **filament**. The other part is the **anther**, which produces the pollen. Each pollen grain is an immature male gametophyte that will eventually produce the male gametes, or sperm.

The fourth ring of flower parts is the **carpels**, which are female reproductive organs. The number of carpels can vary from one to many in different species. Also several carpels may be fused into one structure. There are three

basic parts of a carpel. The top is the **stigma**, where the pollen must land. Often the stigma is sticky or hairy, an adaptation that helps catch the pollen. Below the stigma is a slender stalk, the **style**, which may or may not have a tube through it. Below the style is the **ovary**, containing the **ovules**. The ovules produce the female gametophyte, which eventually produces an egg.

21–9 Pollination The process of **pollination** transfers pollen from an anther to a stigma. Self-pollination can occur if pollen is transferred to the stigma of the same flower. However, there are usually ways that this is prevented, as, for example, when the anthers and carpels of a flower mature at different times. Cross-pollination—the transfer of pollen from one flower to the stigma of another—is the normal process. Cross-pollination is normally meant when the term *pollination* is used.

Insects such as butterflies, bees, and beetles are important in the pollination process of many species of plants.



MAIN IDEA

The two basic methods of pollination are by wind and by animal carrier. Flowers that are animal pollinated always have something to attract the animal, and the flower usually has a special structure that is compatible with the animal pollinator.

SCIENCE BACKGROUND

Many wind-pollinated flowers hang from plants, where the wind is more likely to reach the pollen and pollen in the air will land on the stigmas. The catkin is a typical flower arrangement (inflorescence) for wind-pollinated plants.

A platform is needed for a bee gathering nectar because it cannot perform this task while hovering like butterflies, moths, and hummingbirds. Flowers pollinated by moths are often open only at night. Flies are more common pollinators in high mountain, arctic, and tropical habitats. Bat-pollinated flowers are usually dull-colored, are open at night, have a mouselike odor, and are often suspended on stalks so that it is easy for the bats to get to them.

SCIENCE BACKGROUND

Lilies have a hollow style, and it is believed that the pollen tube absorbs materials from the cells that line the cavity. Most pollen tubes grow very rapidly through the style. The cotton pollen tube requires about 12 h to grow through a style 2 cm long. Growth occurs only at the tip of the pollen tube.

MAIN IDEA

The pollen grain germinates and grows down through the style to the ovule where it enters through the micropyle. Inside the pollen tube the generative cell divides and produces two sperm cells. One sperm unites with an egg cell, which develops into the plant embryo. The other sperm unites with a double-nucleate central cell and forms a $3N$ nucleus, which divides repeatedly and becomes the endosperm that nourishes the embryo and the developing plant. This is a unique double-fertilization process.

There are two basic methods of pollination. One is by wind that blows pollen from one flower to another. Flowers that are wind-pollinated do not have brightly colored sepals or petals. They usually produce tremendous amounts of pollen, which is an adaptation that increases the probability that pollination will occur. Most wind-pollinated plants grow in cold or temperate habitats. The grasses and trees such as oak, birch, and elm are examples of wind-pollinated plants.

The other method of pollination is by animals that carry pollen from one flower to another on some part of their body. Animal pollinators include insects, such as bees, flies, mosquitoes, beetles, butterflies, and moths. Other animal pollinators are hummingbirds and bats.

Plants that are animal-pollinated always have something to attract the animal. Flowers that attract bees and hummingbirds are always brightly colored. Flowers that attract hummingbirds, bees, butterflies, and moths produce nectar. Most have a sweet odor.

Animal-pollinated flowers also usually have special structures that are adapted to the specific pollinator. Flowers that are pollinated by bees often have a platform that the bee can stand on while collecting the nectar. Flowers pollinated by butterflies, moths, and hummingbirds are usually long and tubular in shape. The nectar is at the base of the tube and can be reached only by the long siphoning tube of the butterfly or moth or by the long bill of the hummingbird.

Flowers pollinated by beetles, flies, and mosquitoes often have strong odors. The odors may be fruity or spicy. Also they may be very unpleasant; the odor of rotting meat is very attractive to certain flies and beetles.

21–10 Double fertilization Before fertilization can occur, the pollen grain first must germinate on the stigma. After germination a pollen tube begins to grow down through the style. Inside the pollen tube there are two cells. One, the **vegetative cell**, contains most of the normal cell organelles and is responsible for maintenance and regulation of the pollen tube. The second cell, the **generative cell**, will divide to produce two sperm cells. The female gametophyte, which is in the ovule, undergoes a much more complex process of development.

When the pollen tube reaches the ovule, it enters a small opening called the **micropyle**. Then the vegetative cell and two sperms are released. One sperm enters an egg cell and fertilizes it. This forms a **zygote**, which will develop into the plant embryo.

The other sperm enters a cell called the **central cell**, which has two nuclei. These nuclei and one sperm nucleus fuse to form a $3N$ nucleus. This is called the **endosperm nucleus**. The endosperm nucleus divides hundreds of times and eventually develops into the endosperm, which will nourish the developing embryo.

Note that two fertilization processes occur in the ovule, one in the egg and the other in the central cell. This **double fertilization** is a unique characteristic of the flowering plants.

21-11 Seed and fruit After fertilization the zygote may begin to divide immediately, or it may wait for several days before it begins to divide. But eventually it develops into a plant embryo, with tiny leaves, root tip, and one or two **cotyledons** (kot ə lē'dəns). The cotyledons contain stored food that will nourish the plant later, when the seed germinates and the embryo starts to grow again.

As the embryo reaches the end of its first period of development and becomes dormant, the ovule matures and becomes a seed. The seed coat, or testa, will protect the dormant embryo. Germination of the seed, or the breaking of dormancy, might be delayed for many years.

The first leaves, the cotyledons, and the developing stem can be seen in this photograph of a young bean plant.



MAIN IDEA

The embryo develops into a small plant with one or more cotyledons, then enters a state of dormancy, which may last for many years. As the embryo develops in the ovule, the ovary—sometimes with accessory structures such as the calyx, corolla, or receptacle—develops into a fruit.

SCIENCE BACKGROUND

The seed also contains a variable amount of endosperm that remains after nourishing the first stage of growth of the embryo. The largest seed, the double coconut, weighs up to 20 kg and is dispersed by currents of seawater that can carry it great distances.

Technically fruits are divided into four categories. Simple fruits develop from a single ovary. Aggregate fruits are made up of numerous ovaries (actually carpels), for example, the raspberry. Multiple fruits are made up of several flowers, for example, the pineapple. Accessory fruits include the development of other flower parts, such as the receptacle that becomes the fleshy part of the apple.



These photographs show the development of the ovary into a fruit in a cucumber plant. The seeds are contained within the fruit.



While the ovule develops into a seed, the ovary develops into a **fruit**, which is a seed container. The fruit may be a simple capsule like a pea or bean pod. Or it may contain other good-tasting food such as the fleshy part of a cherry or peach. Sometimes other parts of the flower, such as the receptacle, develop along with the ovary into a fruit. The apple is such a fruit. The part that we eat is the receptacle; the core is the mature ovary. Other fruits are formed when a whole cluster of ovaries mature. The raspberry and blackberry are two examples.

MAIN IDEA

Fruits and seeds have many adaptations for dispersal, which eliminate competition and increase the probability of survival of the seeds. Methods of dispersal include wind, animal ingestion, burial by animals, travel on animal fur, flipping from ruptured capsules, and movement of the whole plant.

21–12 Seed dispersal A seed has a better chance of developing into an adult plant if it lands some distance away from its parent. That way it does not have to compete with its parent for water, nutrients, and a space where light can reach its leaves. The seed has an even greater chance of developing into an adult plant if it lands in a habitat that is not already crowded with other plants.

Most fruits or seeds are adapted in some way for **seed dispersal**, which is the scattering of seeds from the parent plant. Some plants, such as the orchid, produce seeds

that are as small and light as dust. Such seeds can be dispersed for great distances by wind currents.

Many fruits have wings or plumes so that they can be carried by the wind. The fruits of the elm, maple, and ash have winglike structures. The fruit of the dandelion, milkweed, and thistle have fruits with parachutelike plumes.

Many fruits taste good to animals, and that is their best guarantee for dispersal. The good-tasting fruits are eaten, and the fleshy part of the fruit is digested. However, most or all of the seeds pass through the digestive system unaffected by the enzymes. When they pass out in the body wastes, they are someplace other than where they were eaten. In addition, passage through the digestive tract often readies them for growth, and they are surrounded by nature's best fertilizer.

Animals also are responsible for the dispersal of other kinds of fruits. There are fruits with hooks, spines, and various kinds of "stickers" that cling to animal hair or feathers. The cocklebur, sandbur, and beggar-ticks are examples of such fruits.

Nuts are another type of fruit that are dispersed by animals. For example, the squirrel hauls acorns to secret hiding places and buries them for its winter food supply. But seldom are all the acorns dug up and eaten. Thus the squirrel disperses and plants acorns that will grow into oak trees.

Many plants produce capsule fruits, such as bean pods, that coil and twist apart when mature. The coiling and twisting results in the seeds being thrown some distance away from the parent plant. The tumbleweed, a native of Russia that has invaded the North American plains, uses another method of dispersal. The plant grows into the round shape of a ball. When the plant is mature, the wind

SCIENCE BACKGROUND

Plants with good-tasting fruits are not the only ones to be dispersed after passing through an animal's digestive system. Many plants eaten by grazing animals also survive digestion and are dispersed by this method.

The seeds of the milkweed (left) are dispersed by the wind. The seeds of the common burdock have stickers that cling to furry animals.



breaks it off at its base and sends it rolling and tumbling across the plains. And while it rolls and tumbles, it disperses seeds like salt from a bouncing saltshaker.

MAIN IDEA

The two major subgroups of angiosperms are the monocots and the dicots, which have one and two cotyledons, respectively. The monocots usually have parallel-veined leaves, flower parts in threes, fibrous roots, a unique vascular system, and no annual rings. The dicots usually have net-veined leaves, flower parts in fours or fives, a tap root, a unique vascular system, and annual rings if the plants live for more than a year.

MAIN IDEA

An important monocot family is the grass family, which supplies most of our food grains. An important dicot family is the aster family.

Various grasses are the natural food source of many animals. In addition, most of our important grains are domesticated grasses.

21-13 Monocots and dicots There are two major groups of flowering plants. The **monocots** (subclass Monocotyledoneae) have one cotyledon in their seeds. In addition, they usually have leaves with parallel veins and their flower parts arranged in threes, or multiples of three. Monocots have **fibrous roots**, which means that they have several main roots that are all about the same size. They do not produce annual growth rings, and they have a unique vascular system. About one third of the flowering plants are monocots. They include all the grasses and such plants as cattails, lilies, and orchids.

The second major group of flowering plants are the **dicots** (subclass Dicotyledoneae). Dicots have two cotyledons in their seeds. Their leaves have netted veins branching from a central vein, or midrib. Dicot flower parts are arranged in fours or fives. Their root system is a **tap root**, which is a large, primary root with smaller roots branching from it. In addition, the dicots produce a ring of new tissue every year. They also have a unique vascular system. All American trees and shrubs, other than the Ginkgo and the conifers, are dicots. Dicots also include such flowers as the geranium, violet, and sunflower.

21-14 Two important plant families We cannot begin to discuss the hundreds of different families of flowering plants. But there are two families that are of spe-





The sunflower, a member of the aster family, has a composite flower. Only members of the aster family have this type of flower.

cial importance. One, the grass family (family Gramineae), is a monocot family that is important for at least three reasons. First, the grasses cover very large areas of land and provide food for almost all our wild and domestic grazing animals. Second, most of our grains, such as wheat, oats, corn, barley, and rice, are grasses that have been domesticated. These grains are the basic food for most of the world's human population. Third, on farmlands and natural grasslands the fibrous roots of the grass plants hold the soil and help keep it from being blown away by wind and washed away by water. Without grasses much of our valuable farmland and grassland would turn into deserts.

The other important family is the aster family (family Asteraceae), the members of which are dicots. It is the largest plant family in North America and includes such plants as the aster, daisy, dandelion, goldenrod, and sunflower. The flowers of the aster family, called **composites**, are unlike the flowers of any other family. The sunflower is a good example to illustrate the structure of a composite. What seems to be one flower is actually hundreds of flowers. In

SCIENCE TERMS

receptacle
calyx
sepals
corolla
petals
stamens
filament
anther
carpels
stigma
style
ovary
ovules
pollination
vegetative cell
generative cell
micropyle
zygote
central cell
endosperm nucleus
double fertilization
cotyledons
seed dispersal
monocots
fibrous roots
dicots
tap root
composites
disk flowers
ray flowers

SCIENCE BACKGROUND

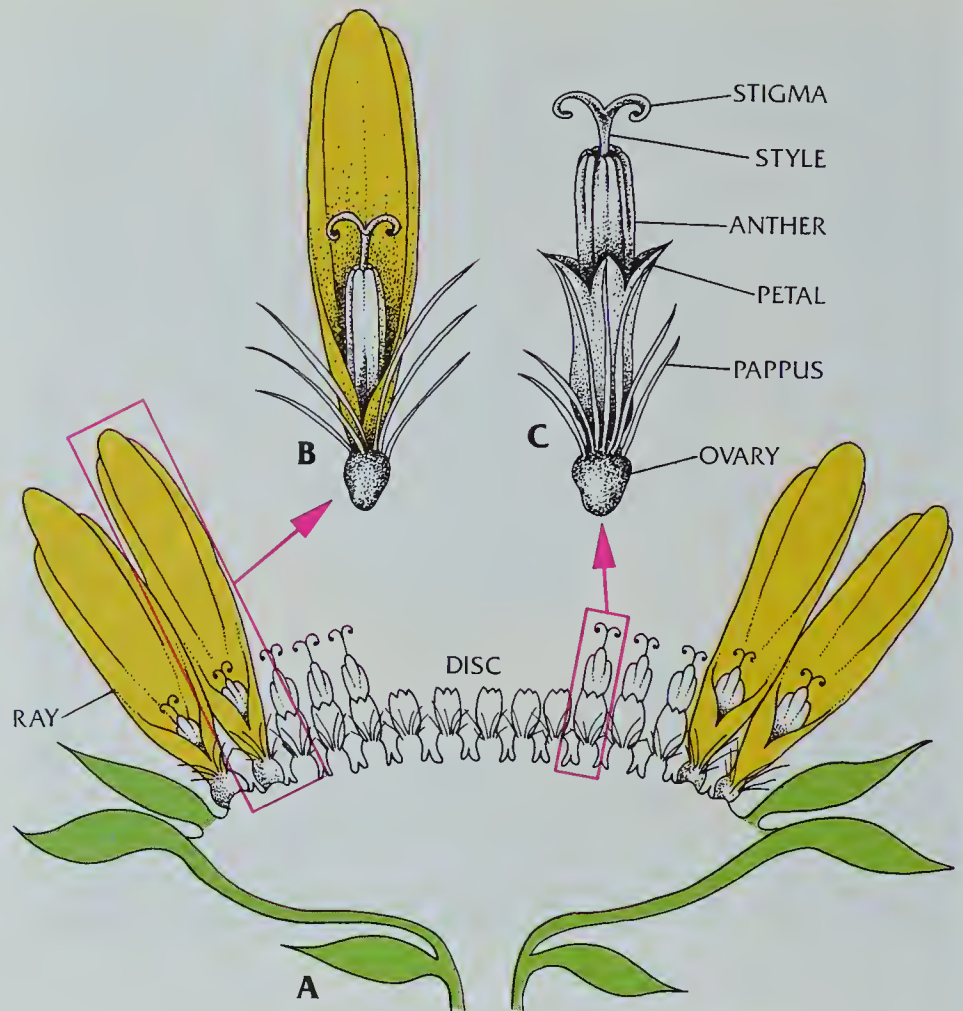
Estimates of monocot species range from 50 000 to 65 000 and of dicots, from 170 000 to 200 000; thus the ratio could vary from $\frac{1}{4}$ to $\frac{1}{3}$. The monocots do not add an annual growth ring because they lack a cambium, which will be discussed in the next chapter.

ANSWERS TO CHECK YOUR FACTS

1. Deeper root systems; better vascular systems; broader leaves; faster reproduction process.
2. The receptacle is the base to which the other parts are attached. The calyx is the outer ring of attachments and is made up of sepals. The corolla is the second ring of parts and is made up of petals.
3. In the petals and sepals. They attract animals that pollinate the flowers.
4. In the anther of the stamen.
5. The stigma is the top of the carpel. Its function is to trap pollen. The style is a slender

FIGURE 21-3

A composite flower is made up of hundreds of smaller flowers. Disk flowers form the center, and ray flowers form the outside ring.



stalk that leads from the stigma to the ovary. The ovary contains the ovules, which produce the female gametophytes and eventually become the seeds.

6. The transfer of pollen from the anther to a stigma of the same plant. Sometimes the reproductive organs mature at different times.
7. Pollen is carried by wind or by animals.
8. The vegetative cell that maintains and regulates the pollen tube, and the generative cell that becomes the sperm cells.
9. The micropyle is the opening in the ovule wall through which the pollen tube enters.

the center of the sunflower there is a cluster of small flowers called **disk flowers**. The disk flowers have a tubular corolla. The other flowers that make up the outside ring of the sunflower have one large yellow petal. These are called **ray flowers**.

CHECK YOUR FACTS

1. List four reasons why the flowering plants are more successful than conifers.
2. Describe the location and relationship of these parts of the flower: sepals, receptacle, corolla, calyx, and petals.
3. Where are nectars produced and what is their function?
4. Where is pollen produced in flowers?
5. Describe the parts of the carpel and their functions.
6. What is self-pollination? How is this sometimes prevented?
7. What two methods of pollination are found in plants?
8. What two cells are in the pollen tube? What is their purpose?
9. What is the micropyle?

SUMMARY

The seed plants are the dominant plants today. The seed plant gametophyte is completely provided for by the sporophyte. Water is not a requirement for fertilization. Seeds are durable, even in extreme conditions. These advantages have allowed seed plants to replace the once-dominant ferns, horsetails, and lycopods. The seed consists of a dormant embryo, the endosperm, and the testa.

Gymnosperms are those seed plants that do not enclose their seeds in a specialized structure (the fruit). Conifers are the major class of gymnosperms. They have woody stems and needlelike or scalelike leaves. Most are evergreen. The oldest, largest, and tallest living organisms on earth are conifers. Conifers produce two types of cones—seed cones and pollen cones. Wind transports pollen from the pollen cone to the seed cone, where it is trapped and drawn inside. After the egg is fertilized, the seed is developed over yet another year. Seeds are finally released to the wind two years after the pollen was produced.

REVIEW QUESTIONS

1. List two reasons for the success of seed plants over non-seed plants.
2. Describe a seed. How do seeds help account for the success of seed plants?
3. On what basis are gymnosperms classified apart from angiosperms?
4. Describe how conifers reproduce.
5. What are the four rings of flower parts found in a typical flower? What functions are performed by these rings?
6. What differences might one observe between a wind-pollinated plant and an animal-pollinated plant? Why?
7. Describe double fertilization. What parts of the seed are formed from this process?

ANALYSIS AND APPLICATION

1. Why is cross-pollination superior to self-pollination?
2. Tomatoes and cucumbers are not commonly thought of as fruits, yet a botanist will say they are. Explain.
3. Growth in most plants occurs in special tissues at the tops of the stem and branches. Grasses are an exception; they grow at joints, some of which are at the lower part of the stem. How would this make grasses better adapted for survival in regions where there are large herds of grazing animals?

ANSWERS TO REVIEW QUESTIONS

1. Seed plants produce a better gametophyte and do not require water for fertilization.
2. A seed consists of an embryo plant; the endosperm, which serves as a food supply; and the testa, a protective coat. Seeds can survive long periods in extreme conditions.
3. Gymnosperms produce seeds that are not enclosed by a specialized structure.
4. See answers 7–9, page 303.
5. The outer ring is the calyx; the second ring is the corolla. These may be brightly colored and produce odors and nectars that attract animal pollinators. The third ring, the stamens, produces pollen. The inner ring, one or more carpels, produces the ovules and seeds.
6. A wind-pollinated plant has no use for bright colors, odors, and nectars and thus lacks attractive flowers. An animal-pollinated plant needs at least one of these devices to attract the right pollinator. A wind-pollinated plant produces much more pollen than animal-pollinated plants to increase the chances for successful pollination.
7. The egg is fertilized to form a zygote. A second sperm enters a $2N$ central cell to form a $3N$ endosperm nucleus.

ANSWERS TO ANALYSIS AND APPLICATION

1. If a population is to survive in a changing environment, it must have the diversity made possible by cross-pollination.
2. They are both specialized structures that house seeds; thus they are fruits.
3. Biting off the stem of a grass will not usually remove the growth tissue.

Investigations 35–36 from *Laboratory Investigations in Biology* can be done with this chapter.

22 *Seed Plant*



OBJECTIVES

- To understand the basic processes by which a plant develops
- To know what is inside a seed and what each part of the embryo will become
- To describe how germination occurs
- To know the different primary growth regions
- To describe the structure and function of primary xylem and phloem
- To define the role of the epidermis
- To understand the nature of secondary growth
- To distinguish between the structure and location of secondary xylem and secondary phloem in a tree
- To understand the significance of growth rings and how they are produced
- To explain the difference between hardwood and softwood

Development

Early Development

22-1 *Development: the nature of the process*

The processes that transform a fertilized egg, or zygote, into a mature adult are called **development**. Usually an organism is considered to be mature when it produces gametes and starts reproducing. But a tree, for example, continues to develop as long as it is alive.

22-2 *Process of development*

Most development occurs at the cellular level. One process of development is **cell division**, which results in an increase in the number of cells. Another process is **cell growth**, the process by which cells get larger. A third process, **cellular differentiation** (dif ə ren shē ā' shən), causes cells to change in form and function from their parent cells. By cellular differentiation, cells in the plant embryo become specialized into water-conducting cells, food-conducting cells, lining or epidermal cells, and so on.

A fourth process of development, **supracellular differentiation**, means "differentiation beyond the cell." During supracellular differentiation, the different specialized cells become organized into tissues, organs, systems, and individuals. Without supracellular differentiation, an individual would be just a mixed-up mass of specialized cells. Supracellular differentiation organizes cells according to each individual's unique genetic code.

22-3 *The plant embryo in the seed* The seed contains a plant embryo that has already undergone some development. The embryo has already developed one or

MAIN IDEA

Development includes all the processes that transform a fertilized egg into a mature adult.

MAIN IDEA

Development includes four processes: (1) cell division, which multiplies cells; (2) cell growth; (3) cellular differentiation, which develops specialized cells; and (4) supracellular differentiation, which results in the formation of tissues, organs, systems, and individuals.

MAIN IDEA

The plant embryo has three regions: the epicotyl, which will develop into the shoot; the radicle, which will develop into the roots; and the hypocotyl, which will become the region in between.

ANSWERS TO CHECK YOUR FACTS

1. The total of all processes that transform a fertilized egg, or zygote, into a mature adult.
2. When it starts producing gametes. No, some organisms continue to develop long after this stage.
3. Cell division, cell growth, and cell differentiation.

MAIN IDEA

Germination is the breaking of dormancy in the embryo and the process that starts the plant growing. Temperature and moisture are factors in causing germination.

SCIENCE TERMS

development
cell division
cell growth
cellular differentiation
supracellular differentiation
epicotyl
shoot
radicle
hypocotyl
germination

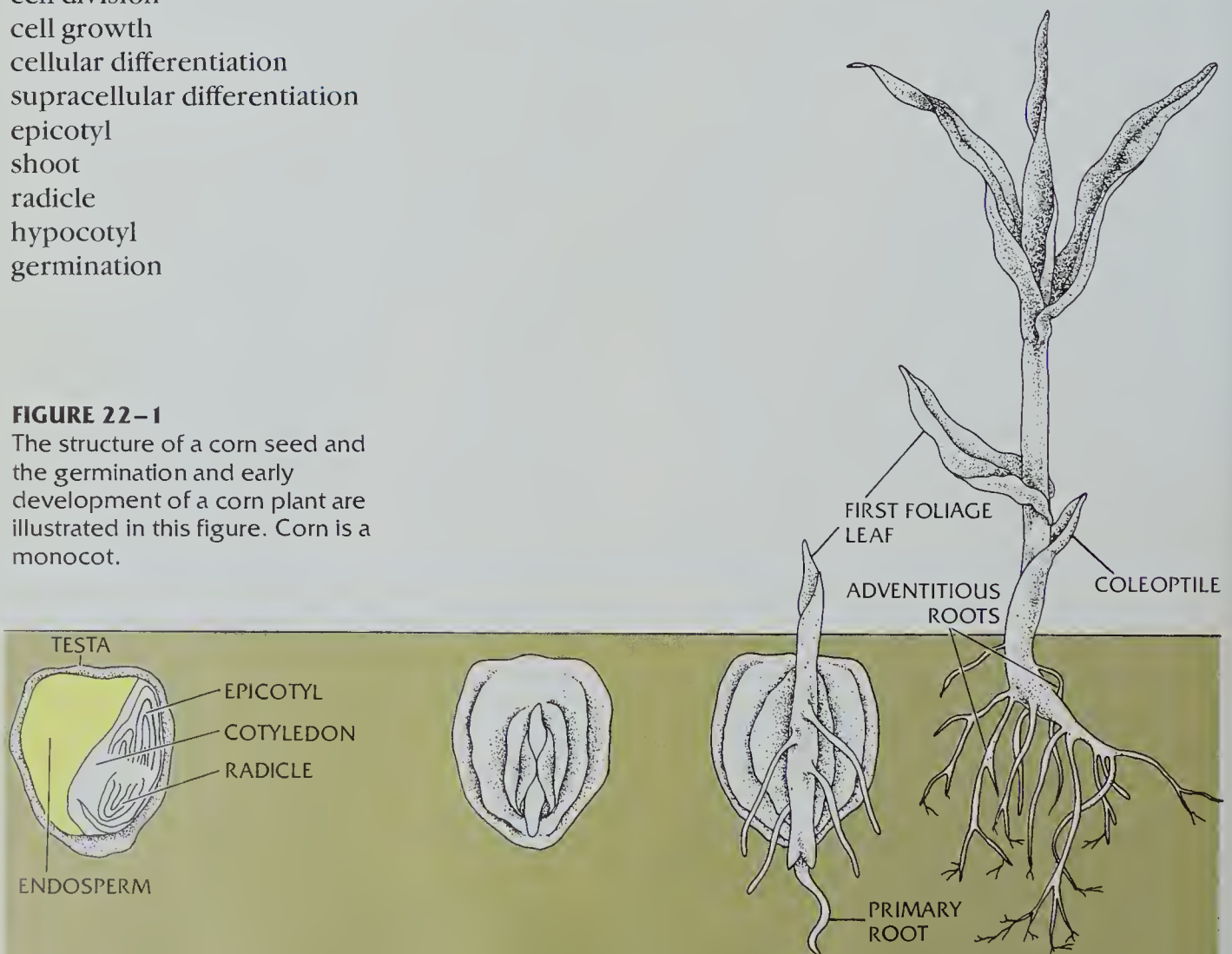
two seed leaves, or **cotyledons**. Also the embryo has well-developed regions above and below the cotyledons. The region above the cotyledons is the **epicotyl** (ep ə kot'əl). It will develop into the **shoot**, the above-ground part of the plant that includes the stem and leaves. Another region of the embryo is the **radicle** (rad'ə kəl), which will develop into the roots. The region between the radicle and the cotyledons is the **hypocotyl** (hī pə kot'əl).

The embryo is normally in a condition of dormancy when it is in the seed. Few or no metabolic activities are going on in the embryo during its dormant stage.

22-4 Germination The beginning of development of the plant embryo after a period of dormancy is called **germination** (jer mə nā'shən). Many factors may be involved in the breaking of dormancy, but the main ones are temperature and moisture. The ideal temperature varies for each seed, but moisture is always needed. Once water gets inside the seed, the dormant embryo usually bursts into an explosion of metabolic activities. Energy is transformed in the cells, using food stored in the endosperm or

FIGURE 22-1

The structure of a corn seed and the germination and early development of a corn plant are illustrated in this figure. Corn is a monocot.

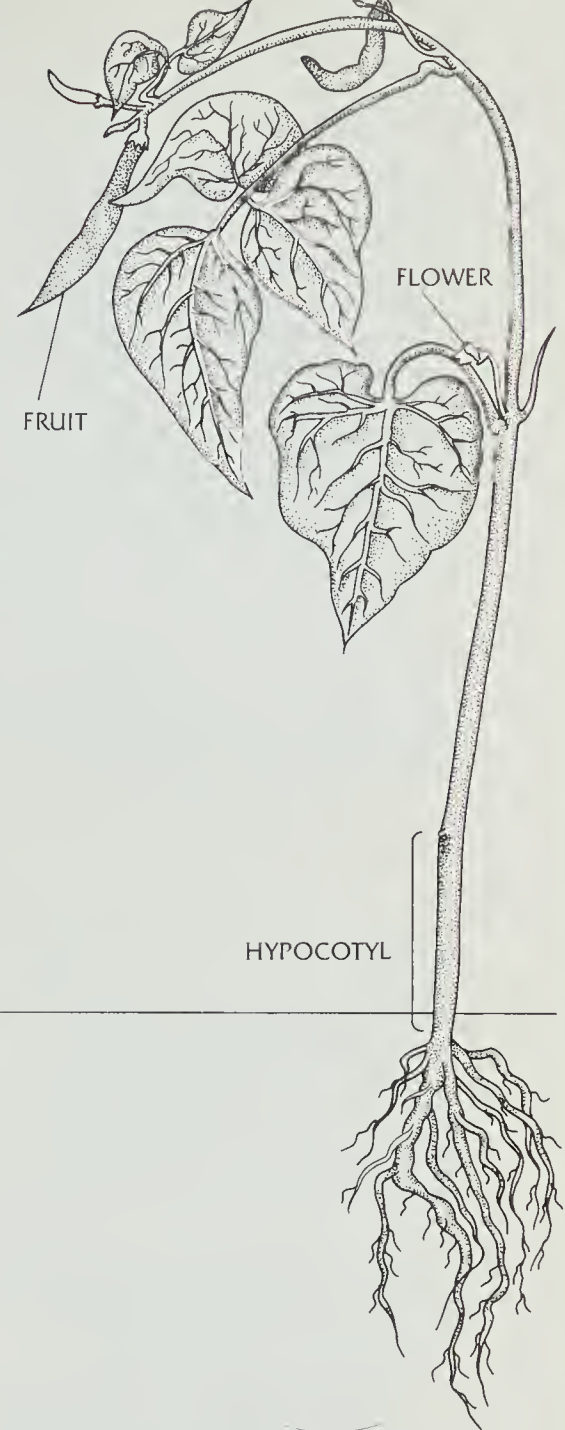
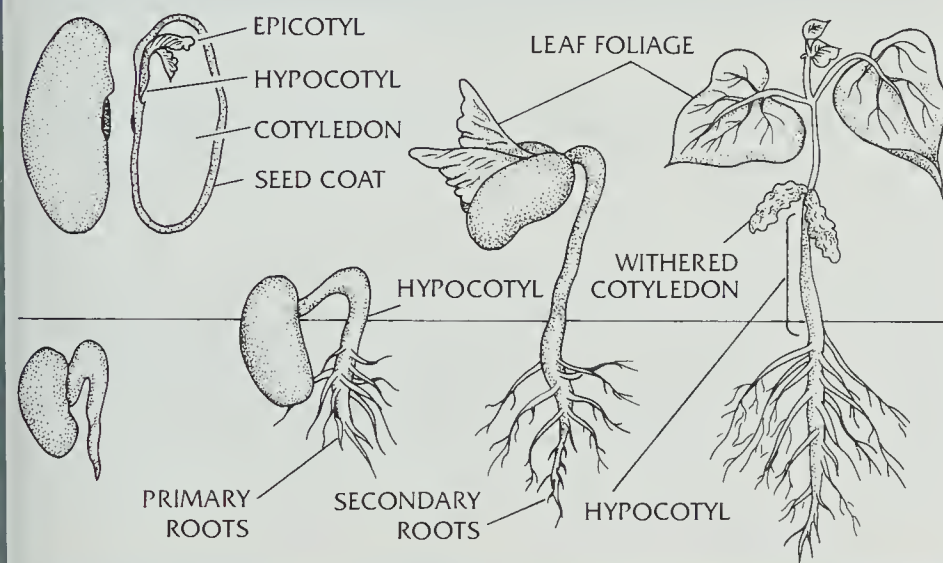


cotyledons. The protein synthesis machinery goes into high gear, producing both structural proteins and enzymes. Usually within hours after taking in water, the seed coat bursts and the young plant is visible as it bursts out of the seed.

Some seeds have to be washed by rainfall before they will germinate. Other seeds have to have their seed coat scratched or cracked. Some need to be heated by a fire or partly digested as they pass through the digestive system of an animal.

Many seeds of temperate regions have to be exposed to one or more periods of freezing and warm temperatures before they will germinate. This is a safety adaptation. Otherwise they might germinate during an unusually warm day in December, then freeze and die a few days later.

FIGURE 22-2 The structure of a bean seed and the germination and early development of a bean plant are illustrated in this figure. Bean is a dicot.



CHECK YOUR FACTS

1. Define *development*.
2. When is an organism usually considered to be a mature adult? Does this hold true for all organisms? Explain.
3. What three processes of development occur at the cellular level?
4. What is cell differentiation?
5. What is supracellular differentiation?
6. What is an epicotyl? What will it form?
7. What is a radicle? A hypocotyl?
8. What factors usually cause dormancy to break? What development stage follows the breaking of dormancy?

4. The process by which cells change in form and function from their parent cells and become specialized cells.
5. The organization of specialized cells into tissues, organs, systems, and individuals.
6. The region above the cotyledons in a seed. The shoot.
7. A region of the embryo that will form the roots. The region between the radicle and the cotyledons.
8. Ideal temperature and water. Germination.

MAIN IDEA

There are two growth regions, called apical meristems, in developing plants. One apical meristem is at the shoot tip; the other, in the tip of the root. The meristems have regions of cell division, cell elongation, and cell differentiation. Growth from the apical meristems is called primary growth.

SCIENCE BACKGROUND

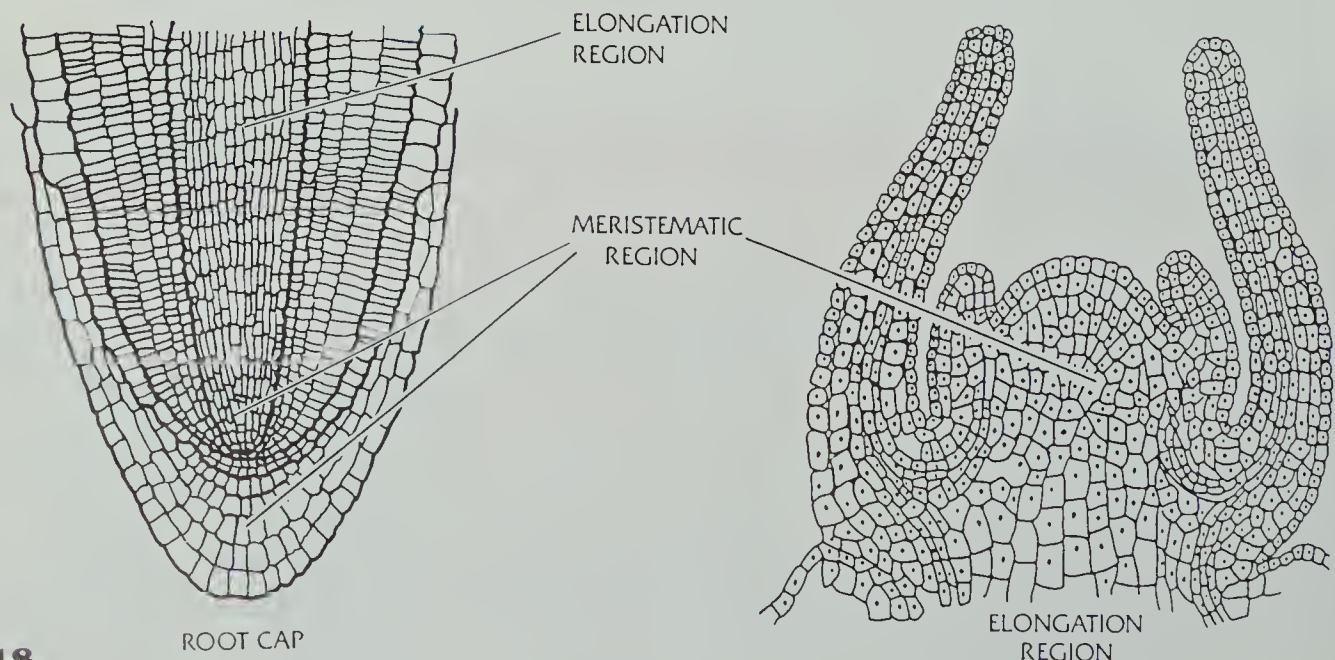
In the meristems, after each division, one of the daughter cells remains in the meristem while the other moves to the plant body.

MAIN IDEA

Primary xylem is one of the tissues of primary growth. It consists of vessel elements and tracheids, which form end to end to make water conducting tubes.

FIGURE 22-3

The locations of the meristematic tissue in a root (left) and a stem (right) are shown in this figure.

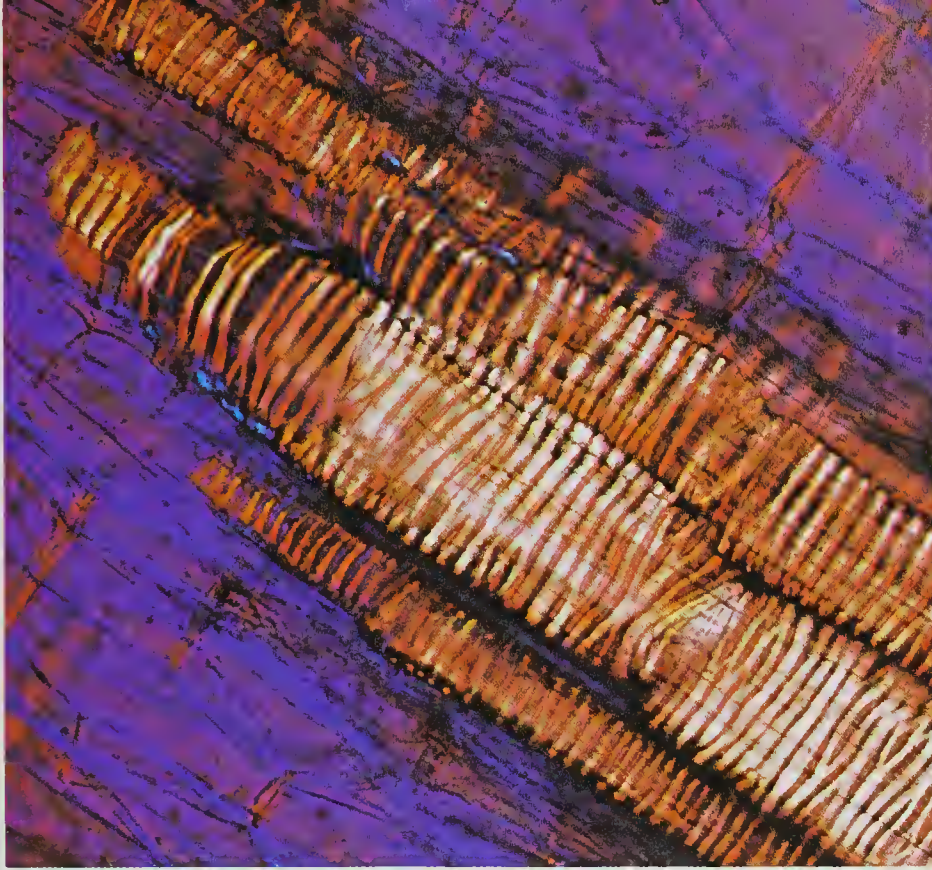


Primary Growth

22-5 Growth regions There are two regions in the embryo of the germinated seed where development is occurring. These are called growth regions, even though the other processes of development—cell division, cellular differentiation, and supracellular differentiation—are occurring. The two growth regions are called **apical meristems** (ap'ə kəl mer'ə stemz). They are located near the root tip and near the tip of the shoot. There are three zones in the region of root apical meristem. One is the true meristematic tissue, where cell division is occurring. Nearby is the zone of elongation, where the cells are growing longer. Just beyond is the zone of differentiation, where cells are becoming specialized. The apical meristem in the shoot is about the same as that in the root. However, the zones of elongation and differentiation are not as clearly defined as they are in the root.

Plant growth that results from development in the apical meristems is called **primary growth**. It is the primary growth that results in the lengthwise development of the plant. This includes the upward growth of the stem and the downward and lateral growth of roots. Primary growth is also responsible for the development of branches, leaves, and flowers.

22-6 Primary xylem The tissues that result from the development of apical meristems are called primary tissues. One important primary tissue is **primary xylem** (zī'lem). Primary xylem is found throughout the root, stem, branches, and leaves. The main function of primary



The spirallike structures at left are xylem vessels in *Coleus*. Xylem tissue is responsible for transporting water in the plant.

SCIENCE BACKGROUND

Technically the vessel members have pits, which are pores through one or both walls, and perforations, which are areas lacking both primary and secondary walls.

Tracheids were named by the Italian physician Marcello Malpighi, who was interested in discovering similarities between plants and animals. While examining xylem tissue, he saw air bubbles escaping and thought they resembled the tracheae of insects, which are the hollow, air-conducting tubes of insects.

MAIN IDEA

The primary phloem, which conducts food downward from the leaves, is made up of sieve tube elements that form end to end to make sieve tubes. Adjacent to the sieve tube elements are companion cells that assist with cellular functions.

xylem is to conduct water throughout the plant. However, it also supports the plant and sometimes stores food.

Primary xylem in flowering plants is made up of two kinds of cells. One is called a **vessel** (ves'əl) **element**. The other is called a **tracheid** (trā'kē id). Both kinds of cells develop secondary walls in addition to the normal cell wall, or primary wall. The secondary walls are usually ring- or spiral-shaped. Their function is to reinforce the interior of the cell and give it more strength. Another characteristic of the vessel elements and tracheids is that they die when they become mature. All that is left is their secondary and primary walls, which perform the actual functions of xylem tissue.

The vessel elements have openings, or pores, in their end walls and along their side walls. Each vessel element is joined end to end with another of its kind. Thus they form a long, continuous tube, called a **vessel** (ves'əl), through which water can move.

The tracheids are long, slender cells that taper at both ends. There are pores in the tracheids, but they are mostly in the end walls. The tracheids overlap at their tapered ends. Thus they also form a continuous tube through which water can move.

22-7 Primary phloem The **primary phloem** (flō'em) is a network of tubes that carries food throughout the leaves, stems, branches, and roots. The cells that make

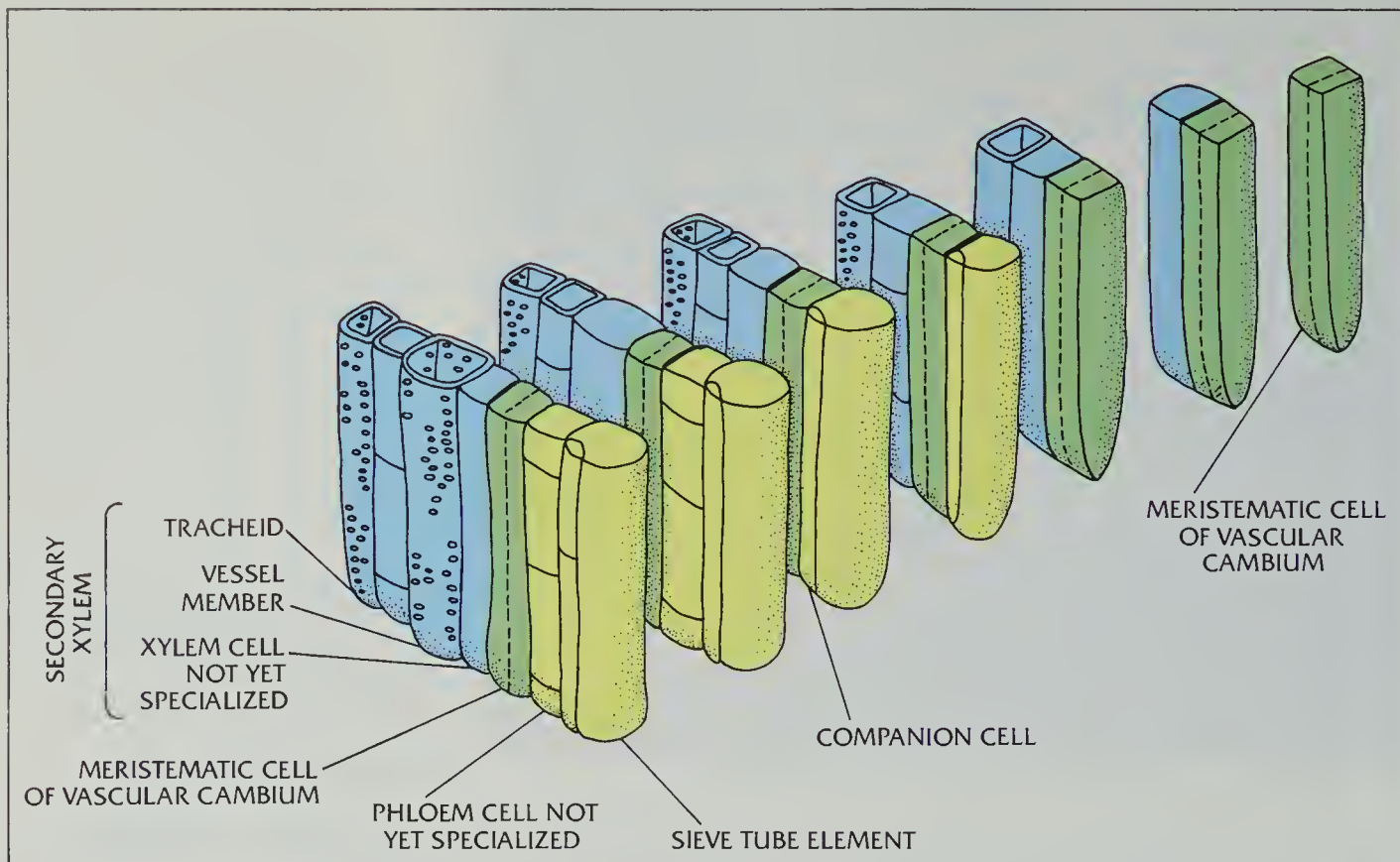


FIGURE 22-4

The development of secondary xylem and phloem from vascular cambium is illustrated in this figure.

SCIENCE BACKGROUND

Some sieve tube elements contain remnants of nuclei. Also they lack ribosomes, Golgi bodies, and microtubules. This suggests that necessary proteins are synthesized in the companion cells.

The sieve elements in the linden tree (basswood) remain alive for five to ten years. Those in certain palms may live for more than a hundred years.

MAIN IDEA

The epidermis is a primary tissue that protects the plant and regulates water loss with stoma, which are pores surrounded by guard cells that expand and contract.

up the phloem in flowering plants are the **sieve** (siv) **tube elements**. Unlike the cells that make up the xylem, the sieve tube elements are still living at maturity, although they lack a nucleus. The sieve tube elements have holes in their end walls. They develop end to end and form a long, continuous tube called a **sieve tube**.

Next to the sieve tube elements there are living cells called **companion cells**, all of which have a complete set of organelles. The companion cells are connected to the sieve tube elements in several places and exchanges occur between them. The companion cells probably assist the sieve tube elements in their activities.

Usually the sieve tube elements and companion cells die after one growing season. If the seed plant lives for more than one year, new phloem tissue will be produced during the next season.

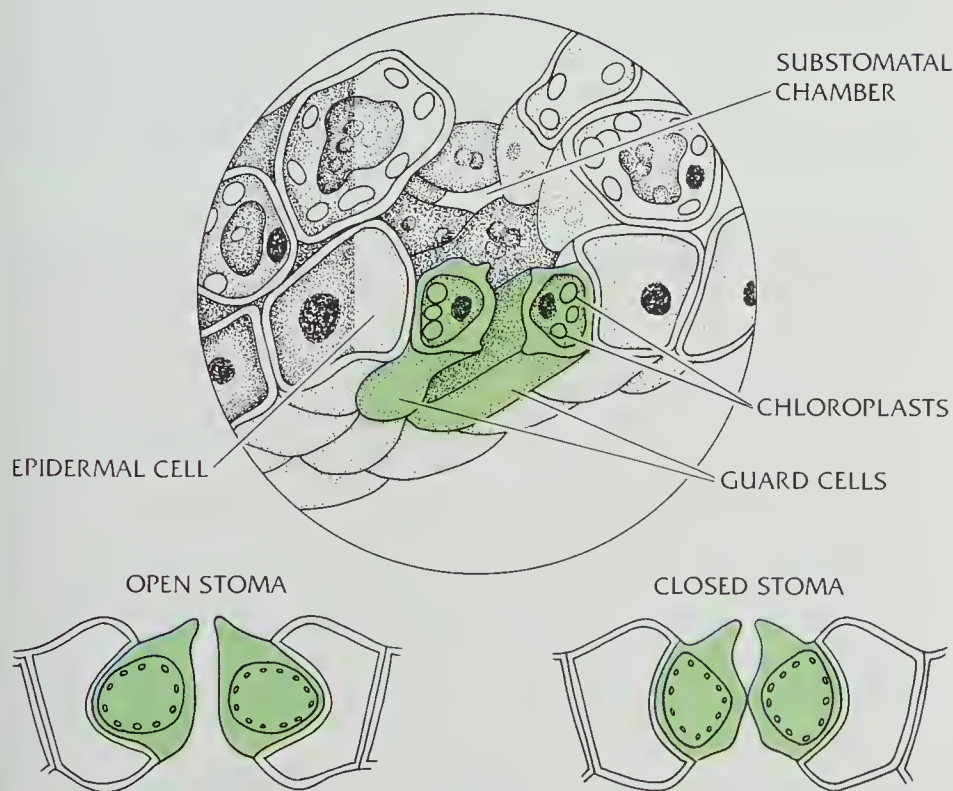
22-8 Epidermis A third primary tissue is that which lines and protects the outside of the plant, the **epidermis** (ep ə der'mis). The epidermis is made up mostly of thin, flat cells. The cells above the ground secrete a **cuticle** (kyū'tə kəl), which is a coating that protects and waterproofs the plant.



Two bands of phloem tissue, containing reddish areas and large, clear cells, are visible in this photograph.

SCIENCE TERMS

apical meristems
primary growth
primary xylem
vessel element
tracheid
vessel
primary phloem
sieve tube elements
sieve tube
companion cells
epidermis
cuticle
guard cells
stoma
transpiration



SCIENCE BACKGROUND

Multiple layers of epidermis are found in some plants, such as in the leaves of the rubber plant, a common houseplant. The multiple epidermis is believed to function as a water-storage tissue.

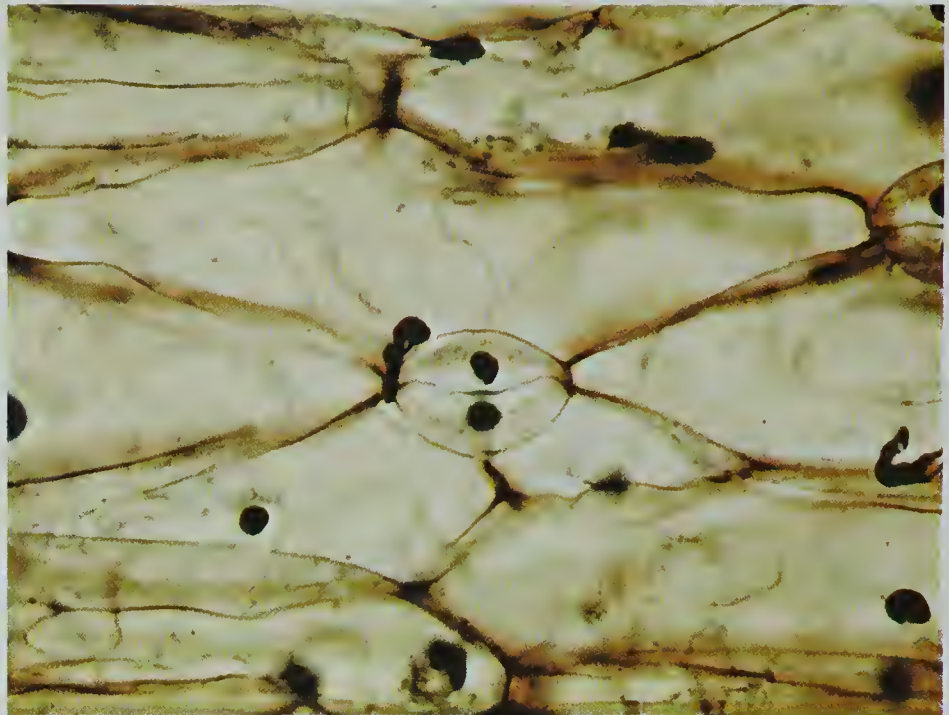
Most teachers will recognize an unfamiliar definition of the term *stoma*. In past years the actual pore of the leaf was considered to be the stoma. After surveying modern literature, it seems more appropriate to define the term as the whole stomatal apparatus, which includes the guard cells. The guard cells enlarge and contract as a result of a difference in turgor pressure, which will be discussed in the next chapter.

FIGURE 22-5 The location of a stoma on the underside of a leaf is indicated in this figure.

ANSWERS TO CHECK YOUR FACTS

1. Apical meristems. The root tip and the shoot tip.
2. (a) The meristematic tissue where cell division is occurring; (b) the zone of elongation, where cells are growing longer; and (c) the zone of differentiation, where cells become specialized.
3. Growth that results from development in the apical meristem. It results in the

Two small guard cells are visible in the center of the photograph at right. The guard cells control the size of the stoma.



lengthwise development of the plant and the development of branches.

4. In the roots, stems, branches, and leaves. It conducts water, sometimes food and provides support.
5. The cells that compose primary xylem. They join end to end, and they have pores that enable water to pass from one to the next.
6. A network of tubes for transporting food throughout the plant. Sieve tube elements.
7. This cell lacks a nucleus. It develops end to end with other sieve tube elements. It has pores in its end walls. It is probably not self-sufficient.
8. Cells connected to the sieve tube elements.
9. The primary tissue that lines the outside of the plant. Epidermal cells produce a waterproof cuticle.
10. A stoma is a pore surrounded by two specialized epidermal cells called guard cells. The stoma regulates transpiration.

On the leaves, and often on the stems, the epidermis also has specialized cells called **guard cells**. The guard cells enclose a pore through which water evaporates and gases are exchanged. Unlike the other epidermal cells, the guard cells contain chloroplasts. The unit consisting of two guard cells and a pore is called a **stoma** (stō'mə) (pl. *stomata*). The guard cells regulate the size of the pore by expanding and contracting. This, in turn, mainly controls the rate of water evaporation, called **transpiration** (transpə rā'shən), from the leaves or stem.

CHECK YOUR FACTS

1. What are the two growth regions of a plant embryo called? Where are they found?
2. Name and describe the three zones of the root apical meristem.
3. What is primary growth? What results from primary growth?
4. Where is primary xylem found? What is its function?
5. What are vessel elements and tracheids? How do they function?
6. What is primary phloem? What cell makes up the primary phloem?
7. Describe a sieve tube element. Is it self-sufficient?
8. What are companion cells?
9. What is the epidermis? How does it waterproof the plant?
10. Describe the structure and function of a stoma.

Secondary Growth

22-9 The nature of secondary growth Some plants continue to grow year after year and produce woody stems. As they grow taller by primary growth, they also increase the width of their stems, branches, and roots. This increase in width is called **secondary growth**.

Secondary growth is produced by **lateral** (lat'ər əl) **meristems**, which are of two types. One, the **vascular cambium** (vas'kyə lər kam'bē əm), produces secondary xylem and phloem. These are vascular tissues like primary xylem and phloem. The other lateral meristem, called **cork cambium**, produces **cork**, a protective layer that replaces the epidermis in the stems of woody plants.

22-10 The vascular cambium The vascular cambium is a thin layer of cells between the primary xylem and the primary phloem. It is outside the xylem and inside the phloem. As the cells of the vascular cambium divide, secondary xylem is produced on the inside and secondary phloem, on the outside. However, more xylem is produced than phloem. Thus the vascular cambium is pushed farther out from the center of the stem. This movement crushes and destroys the primary phloem, which is usually dead and nonfunctioning anyhow.

Over a period of years, the secondary xylem becomes the woody part of the shrub or tree. Usually the phloem dies each season. The dead sieve tubes are crushed as the stem grows wider in diameter, with only fibers of the phloem remaining. While water may be conducted through a large part of the xylem, or wood, food transportation occurs only in the thin layer of living phloem near the outside of the stem.

The vascular cambium also produces conducting tissues that run horizontally across the stem. These horizontal conducting tissues, called **rays**, radiate out from the center of the stem like the spokes of a wheel.

22-11 The cork cambium The cork cambium is near the outside of the stem. It produces cork, which is impermeable to water and gases. However, the cells underneath the cork must exchange gases with the air. This is done through small pores in the cork called **lenticels** (len'tə sels).

Bark is the total of all the tissues that are outside the vascular cambium. This includes the secondary phloem, fibers from crushed phloem, cork cambium, cork, and layers of dead tissue. Usually bark has two distinct layers—the

MAIN IDEA

Secondary growth is produced by lateral meristems and causes plants to increase their width. There are two types of lateral meristems: vascular cambium, which produces secondary xylem and phloem, and cork cambium, which produces cork.

MAIN IDEA

The vascular cambium produces more secondary xylem than secondary phloem; hence it is pushed out from the center of the stem in a growth process that widens the tree. This movement crushes the older layers of phloem. Over the year the tree is made up mostly of secondary xylem; the dead fibers of phloem remain with only one thin layer of living phloem. The vascular cambium also produces rays, which are horizontal conducting tissues.

MAIN IDEA

The cork cambium produces cork, which protects the outside of the tree. Lenticels, which are pores in the cork, allow gas exchange to occur. Bark is the total of all tissues outside the vascular cambium and consists of living tissue, or inner bark, and dead tissue, or outer bark.

SCIENCE TERMS

secondary growth
lateral meristems
vascular cambium
cork cambium
rays
lenticels
bark
annual rings
heartwood
sapwood
softwood
hardwood

SCIENCE BACKGROUND

Another term for *early wood* is *spring wood* and for *late wood*, *summer wood*. Some trees growing by a river show only faint annual rings that result from temperature differences throughout the growing season. A late wet period during the summer could cause another growth of early wood, and hence a false ring. Annual rings are not found in many tropical woods because growth conditions are uniform throughout the year.

Almost any board can be brought to class and annual rings observed on the end of the board.

MAIN IDEA

Because of the difference in available moisture in temperate climates between spring–early summer and late summer–autumn, there is a difference in the size of secondary xylem cells that are produced. This difference is observed as light and dark bands called annual growth rings that can be used to estimate the age of a tree.



Lenticels, small pores in the cork, permit underlying cells to exchange gases with the atmosphere.

inner bark, which includes the living tissues, and the outer bark, which is made up entirely of dead material.

22–12 Secondary growth patterns The wood of a tree is secondary xylem tissue, produced by the vascular cambium. In temperate climates the secondary xylem is produced only during the growing season in late spring, summer, and early autumn. However, growth of secondary xylem usually follows two patterns through the growing season. During the spring and early summer, when plenty of moisture is normally available, the cells that make up the xylem grow large. The wood that is produced is called early wood.

During the dry periods of late summer and autumn, the xylem cells are much smaller and the wood is called late wood. Therefore there are two types of secondary xylem produced during each growing season, early wood and late wood.

When a cross section of a cut tree is examined, each season's growth is visible as a series of rings. These rings are called **annual** (an'yü əl) **rings**. Each one has a light section, which is the early wood, and a dark section, which is the late wood. By counting the annual rings in a cross section, the approximate age of a tree can be determined. The exact determination of age is impossible because of false rings that sometimes develop during an unusual growing season. Also, by comparing the widths of each year's early and late wood, historical evidence of growing conditions can be determined. By studying the annual rings in very old trees, indirect evidence of seasonal variations in climate can be obtained for the past several thousand years.

22-13 Kinds of wood Most trees develop two types of wood as they grow older. In the central part of the tree the xylem gradually becomes filled with pigmented mate-



ANSWERS TO CHECK YOUR FACTS

1. The increase in width of roots, stems, and branches. Lateral meristems.
2. Vascular cambium produces secondary xylem and phloem. Cork cambium produces cork.
3. Outside the xylem and inside the phloem. It produces more secondary xylem on the inside than secondary phloem on the outside; thus the pressure from the inside is greater and the vascular cambium is pushed outward.
4. Secondary xylem. No.
5. Only in the living phloem.
6. Connecting tissues produced by the vascular cambium that radiate outward from the center of the stem.

MAIN IDEA

The pigmented part of the secondary xylem is nonfunctional and is called heartwood; the unpigmented portion functions as water-conducting tissue and is called sapwood.

7. Near the outside of the stem in regions recently occupied by epidermis. Cork helps protect the inner parts of the stem.
8. Pores in cork that allow the stem to exchange gases with the atmosphere.
9. All the tissues outside the vascular cambium. Inner bark is living tissue, while outer bark is dead tissue.
10. The different amounts of moisture between spring-early summer and late summer-autumn result in a different cell size in the secondary xylem—large in the spring and small in

Annual rings, formed by the growth of secondary xylem, are clearly visible in this photograph of a birch stem.

the fall. This varying cell size appears as alternating light and dark rings, one pair of rings for each growing season.

11. Heartwood is filled with pigmented material and no longer conducts water. Sapwood appears lighter and still transports water.

ANSWERS TO REVIEW QUESTIONS

1. Cell division, cell growth, cellular differentiation, and supracellular differentiation.
2. Supracellular differentiation produces tissues, organs, systems, and individuals from groups of specialized cells. Cellular differentiation forms specialized cells from non-specialized parent cells.
3. The epicotyl, which forms the shoot, and the radicle, which forms the roots.
4. The beginning of development of a plant embryo after a period of dormancy. Usually a combination of temperature and water.
5. They are the regions where primary growth occurs. They consist of meristematic tissue, a zone of elongation, and a zone of differentiation. Apical meristems are located at the shoot tip and at the root tip.
6. Primary growth is the lengthwise development of the plant; secondary growth is the thickening of stems, roots, and branches. Primary growth originates in the apical meristems; secondary growth is produced by lateral meristems.
7. It is composed of vessel elements and tracheids. Both types of cells have secondary walls and both form long continuous tubes by joining end to end with other cells. Pores in the end walls allow water to

materials that give it a dark, reddish appearance. This wood, called **heartwood** (härt'wüd), no longer functions as a conducting tissue for water. The remaining portion of the wood, called **sapwood** (sap'wüd), is much lighter in color and continues to conduct water.

Throughout the years it has become the practice to use the term **softwood** (sôft'wüd) for the wood of conifer trees. The term **hardwood** (härd'wüd) is used to describe the wood of dicot trees. Actually neither name describes how hard or how soft each type of wood really is. Hemlock, which is a softwood, is quite hard. Balsa wood, which is a hardwood, is the softest and lightest wood known.

CHECK YOUR FACTS

1. What is secondary growth? What produces it?
2. What is produced by the two types of lateral meristems?
3. Where is the vascular cambium located? Why is it pushed farther from the center of the stem?
4. What is the woody part of a tree? Are these cells alive?
5. Where does food transportation occur in a tree?
6. What are rays?
7. Where is cork found? What is its function?
8. What are lenticels?
9. What is bark? How is it divided into two layers?
10. How are annual rings formed?
11. Explain the difference between heartwood and sapwood.

SUMMARY

The total of all the processes that transform a zygote into a mature adult is called development. Cell division, cell growth, cellular differentiation, and supracellular differentiation are the different processes of development. The dormant plant embryo consists of the cotyledons; the epicotyl, or immature shoot; the radicle, or immature root system; and the hypocotyl. Water and temperature usually are the factors that cause dormancy to end and development to begin—a stage called germination. Plants have developed many different adaptations that require other conditions before germination can take place.

Primary, or lengthwise, growth originates in the apical meristems located in the shoot and root tips. The primary tissues produced are primary xylem, which transports water; primary phloem, which transports food; and epidermis, which lines and protects the plant and controls transpiration.

Xylem tissue is made of sieve tubes. These are long series of connected sieve tube elements.

Secondary growth is the widening of stems, roots, and branches. This growth occurs in the lateral meristems, namely the vascular cambium and the cork cambium. The vascular cambium produces secondary xylem and secondary phloem. It also produces rays that fan out horizontally from the center of the stem. Bark is the total of all the tissues that are outside the vascular cambium. Alternating periods of moisture and dryness cause the wood, or dead xylem, of trees to appear as rings of alternating light and dark wood. These annual rings can be used to estimate the age of the tree and the climatic conditions through which it has aged. Wood that can no longer conduct water is heartwood; the remaining wood is sapwood. Wood from conifers is called softwood, while dicot wood is called hardwood. Neither name reflects the true degree of hardness of these woods.

REVIEW QUESTIONS

1. List the four types of development processes.
2. Distinguish between supracellular and cellular differentiation.
3. What regions of the embryo are developed at the seed stage? What will these regions produce?
4. What is germination? What causes a seed to germinate?
5. Describe apical meristems. Where are they located?
6. Distinguish between primary and secondary growth. What produces each type of growth?
7. Describe the structure and function of xylem tissue.
8. Where is phloem found? What function does it serve?
9. Discuss the relationship between sieve tube elements and companion cells. How long do these cells live?
10. What is the function of the epidermis? How does it control water loss from the plant?
11. Name three products of the vascular cambium.

ANALYSIS AND APPLICATION

1. Describe the appearance of annual rings grown over five years of wet springs and dry autumns and then five years of unusually dry springs and falls.
2. When trees are girdled (a section of the bark and phloem removed completely around the trunk), the area above the cut continues to grow while the area below the cut does not. The plant eventually dies. Explain.
3. Why is it hard to determine the age of many tropical trees from the annual rings they produce?

pass through the xylem tissue. Water transport is the main function of xylem tissue. Support is another function.

8. It is nearly the outermost living tissue of the stem, branches, and roots. Phloem forms a network in the leaves. Phloem transports food throughout the plant.

9. Companion cells are connected to sieve tube elements and exchanges occur between them. Since the sieve tube elements lack a complete set of organelles, the companion cells assist in their cellular activities. They normally live one growing season.

10. It lines and protects the plant, waterproofs the plant, and controls transpiration. Specialized guard cells control the size of the pores and thus the amount of water that can pass.

11. Secondary xylem, phloem, and rays.

ANSWERS TO ANALYSIS AND APPLICATION

1. The inner rings would have relatively large light rings compared to the outer rings. The cross-sectional radius of wood produced in the first five years would be greater than that produced in the second five years.

2. The girdle cuts off the food supply from the leaves to the lower plant, thus the area below the cut does not grow. The xylem is unharmed and it still supplies water from the roots to the upper plant. The plant dies because the roots eventually starve.

3. They may have several alternating periods of wetness and dryness in one year; thus annual rings would not represent years, but periods of rainfall.

Investigations 37–38 from *Laboratory Investigations in Biology* can be done with this chapter.

23 *Hormones and Plant*



OBJECTIVES

- To understand the general nature of hormones
- To explain how the phototropic response of plants is controlled by auxins
- To understand the concept of apical dominance
- To appreciate the economic value of auxins
- To explain how ethylene is used to control the ripening of fruits
- To appreciate that gibberellins can be used as growth stimulators
- To know that cytokinins are growth stimulators that counter the effects of auxins
- To understand the two growth responses, phototropism and geotropism
- To explain the concept of photoperiodism

Responses

Plant Hormones

23-1 What are hormones? Hormones (hôr'mōnz) are chemicals that are produced by one tissue and transported to other tissues where they cause some kind of response. They are found in both plants and animals. Their function is to regulate or control different body activities.

Hormones are normally produced in extremely small quantities. Sometimes the amount of hormone produced will determine the kind of response that is produced. One quantity might *stimulate* a process, while another quantity might *inhibit*, or slow down, the same process.

23-2 The discovery of auxins One group of plant hormones includes a variety of closely related chemicals called **auxins** (ôk'sinz). The effects of auxins were discovered after a famous experiment by Charles Darwin and his son. The Darwins were experimenting with seedlings. They were trying to determine why plants always grow toward the light. This response is called **phototropism** (fō tōt'rə piz əm). In one experiment they placed an opaque cap over the top of a seedling and found that it did not bend toward the light. In a second experiment they placed an opaque collar down lower on the stem and found that that had no effect—the seedling grew toward the light.

Many years later a Dutch botanist, Fritz Went, discovered why the Darwins' seedlings reacted as they did. He cut off the tips of oat seedlings and placed them on pieces of agar,

MAIN IDEA

Hormones are chemicals that are produced in one tissue and transported to other tissues where they cause some kind of response. They are produced in small quantities, and the quantity often governs the type of response.

MAIN IDEA

Auxins were discovered as a result of investigations of the phenomenon of phototropism, which is caused by auxins stimulating growth on the shaded side of the plant.

SCIENCE BACKGROUND

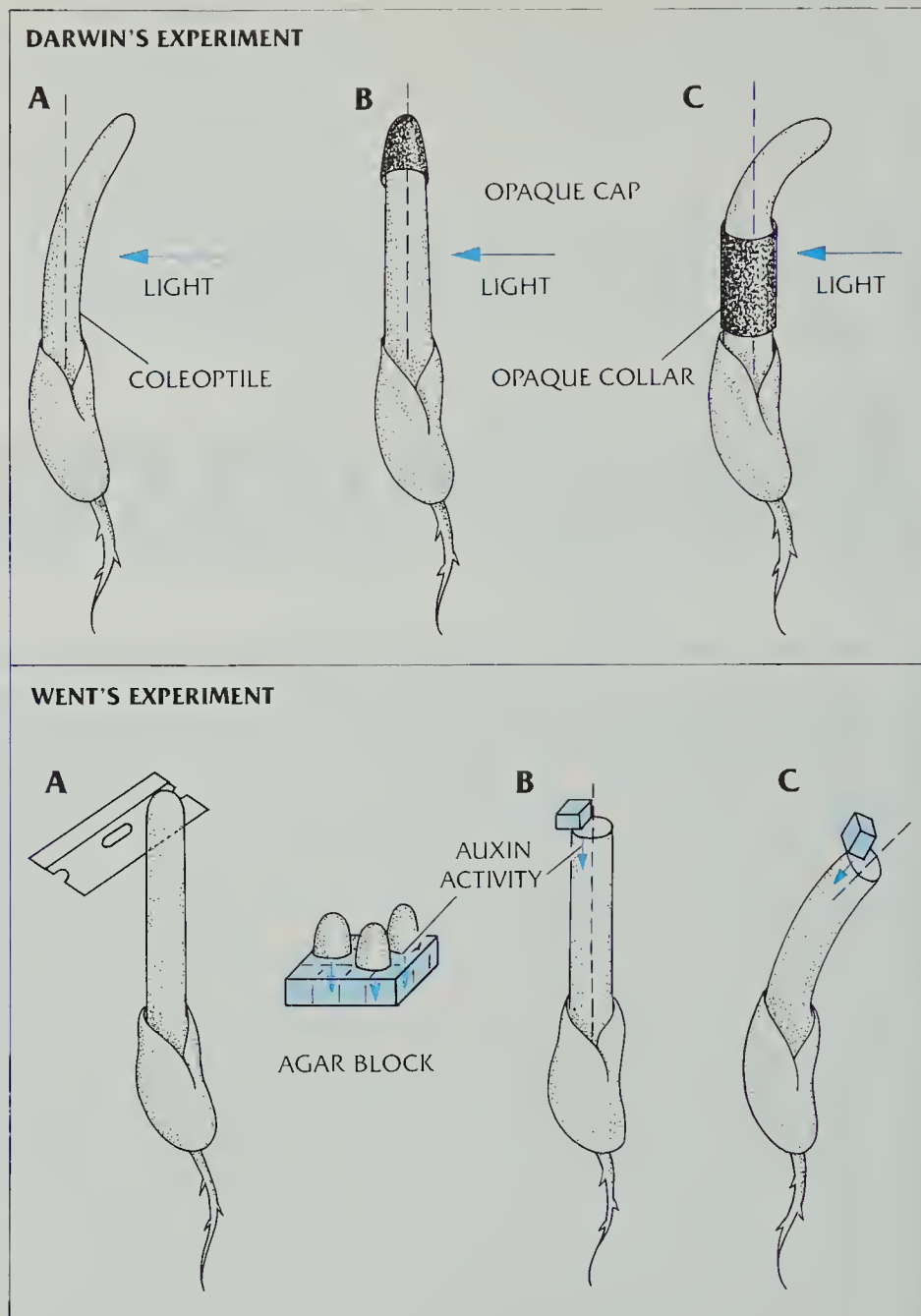
The term *hormone* comes from a Greek word and means "to excite." Unfortunately excitement is just one action of hormones; they also may have an inhibitory effect.

FIGURE 23–1

The experiments of Darwin and Went showed that shoot tips produced a substance that caused the shoot to bend toward light.

SCIENCE BACKGROUND

Fritz Went made his discovery while working as a graduate student in his father's laboratory at Utrecht, Netherlands. He coined the term *auxin* after the Greek word *auxein*, which means "to increase." The most common auxin is indoleacetic acid (IAA). The mechanism of auxin action is as follows: The auxin weakens the polysaccharides in the cell walls, allowing more water to enter the cell and, in turn, increasing the turgor pressure, causing enlargement—specifically elongation. Actually auxin's effect is indirect—it causes the cells to secrete substances that break bonds in the cell wall polysaccharides. After a time the cell wall becomes rigid, thus stopping the elongation.



which is a gelatinlike substance. The cut edges were left on the agar for about an hour. Then he cut the agar into little blocks and placed the blocks on one side of each of the cut shoots. The shoots were kept in the dark, but within an hour they had bent away from the side on which the blocks were placed.

Went concluded that hormones produced in the tip caused the shoots to bend. But what does light have to do with the response? Botanists and chemists eventually isolated the hormones that caused the phototropic responses. Some have also been manufactured synthetically. These hormones, which are related chemicals, are auxins. We

know now that auxins are produced by the tip of a plant and that they flow downward. Their action is to cause cells to elongate, or grow longer. But light causes the auxins to move from the lighted side of the plant to the shaded side. The result is that the cells on the shaded side of the plant grow longer than those on the lighted side. That causes the plant to bend toward the light.

23-3 Auxins and apical dominance The auxins are produced in the apical meristems of plants that have terminal buds. The auxins cause cells in the meristem's zone of elongation to grow longer. The auxins also affect the lateral buds of plants. The lateral buds have meristems that can develop into branches. But the auxins from the terminal buds inhibit the growth of lateral buds. The auxins keep branches from developing, or cause a decrease in the number that are produced. This effect of auxins from the apical meristems is called **apical dominance** (dom'ə nəns).

Apical dominance can be demonstrated in many plants. Just pinch off the terminal bud of a plant such as *Coleus*. The lateral buds begin to grow rapidly, and soon the plant is bushier.

23-4 Other effects of auxins Auxins are produced in leaves but they have no apparent effects upon leaf growth. Instead, they seem to control the events that result in the falling off of leaves, or **abscission** (ab sizh'ən). Decreased auxin production causes a gradual weakening of cells at the base of the leaf. Eventually the cells break down and the leaf falls off, or abscisses.

Orchard fruits also fall off, or absciss, from trees by a process similar to leaf abscission. Sometimes they absciss before they are ready to be picked. By spraying with auxins, the abscission can often be delayed until the fruits are ready for picking.

A synthetic auxin called 2,4-D is widely used as a **herbicide** (hēr'bə sīd), which is a chemical that kills plants. It is sprayed on weeds, and they are stimulated to grow so rapidly that they die. Strangely 2,4-D affects broad-leaved plants but not grasses. Therefore it is widely used to kill weeds, such as dandelions, that invade grassy lawns.

23-5 Ethylene Ripe fruits give off **ethylene** (eth'ə lēn), which speeds up the ripening process in unripened fruits. It is not known exactly how the ethylene causes such a response. Banana producers and shippers make good use of ethylene in their business. Bananas are picked

SCIENCE BACKGROUND

Potatoes have "eyes" that are really buds. When treated with auxins, the bud development is inhibited. This makes it possible to store potatoes for up to three years.

MAIN IDEA

Auxins are produced in the apical meristems where they stimulate elongation but inhibit lateral bud development—an effect called apical dominance.

MAIN IDEA

Auxins control abscission, and they are used commercially to control the abscission of fruits. Auxins are also used as herbicides.

MAIN IDEA

Ethylene stimulates the ripening of fruits; it is used commercially to time fruit ripening for ideal market conditions. Ethylene is also used commercially to control abscission of fruits.

SCIENCE TERMS

hormones
auxins
phototropism
apical dominance
abscission
herbicide
ethylene
gibberellins
cytokinins

SCIENCE BACKGROUND

The formula for ethylene is C_2H_4 . It is extremely effective in small quantities, for example, as low as 1 part in 10 million parts of air. Treatment with auxin causes a rapid increase in the production of ethylene by some plant tissues, and perhaps some of the effects credited to auxins are really caused by ethylene.



Bananas are picked while they are still green. They are exposed to ethylene at just the right time to be ripe for marketing.

SCIENCE BACKGROUND

The gibberellins were discovered by Japanese scientists who were studying the "foolish seedling disease" of rice. The disease is caused by a fungus, and the effect is a rice plant that grows taller than normal but is too spindly to stand up. The substance that affected the plant was eventually isolated from the fungus *Gibberella fujikuroi*, hence the name for the hormone. Since then more than 20 gibberellins have been identified from many different species of seed plants.

while they are still green. As they are being shipped they are exposed to ethylene at just the right time so that they will be ripe when they arrive in the supermarkets.

Fruit producers also have to worry about the production of ethylene in places where fruit is stored. Storage facilities have to be carefully ventilated. Often carbon dioxide is added to the air. This gas counteracts the effect of ethylene.

Ethylene can also affect the abscission of fruits. Orange growers have applied this discovery in their orchards. By spraying the trees with a chemical that breaks down into ethylene, all the fruit becomes ready to abscise at almost the same time. That way mechanical pickers, which shake the oranges and cause them to drop, can harvest the entire crop at one time.

Ethylene has an interesting effect upon many flowers—it causes them to wilt. Flowers should not be put near ripe

fruit, especially apples. Also flowers should not be stored in a refrigerator with ripe fruit.

23-6 The gibberellins Another group of plant hormones includes several closely related chemicals called **gibberellins** (jib ə rel'inz). The gibberellins are growth stimulators, causing increased cell division and cell elongation. They are very effective in treating dwarf plants, such as the dwarf pea plants that Mendel used in his genetic experiments. When treated with gibberellins, the dwarf plants grow to the size of normal plants.

Gibberellins are present in seeds of the grass family. When water is taken into those seeds, the gibberellins are released. They stimulate other cells in the seed to synthesize enzymes. The enzymes, in turn, break down the starch of the endosperm into simple sugars that can be used for energy by the developing embryo.

23-7 Cytokinins The **cytokinins** (sī tō ki'nins) make up another group of hormones. They stimulate cell division in plants. They get their name from **cytokinesis** (sī tō ki nē'sis), which is one name for cell division.

The cytokinins have been found in numerous plants, where their role is to stimulate stem and root growth. But they also have an interesting effect upon leaves. They keep leaves from aging. A drop of liquid containing a cytokinin placed on an aging, yellowing leaf causes the leaf to turn green. Cytokinins have an opposite effect of auxins on some parts of a plant. For example, when cytokinins are placed on lateral buds, the buds may start developing. They may develop even though the terminal bud is present and its auxins are exerting their apical dominance.

CHECK YOUR FACTS

- 1. What are hormones? What is their function?
- 2. What is phototropism?
- 3. What is the effect of auxins on cells in the stem?
- 4. Why does a plant bend toward light?
- 5. Explain what is meant by *apical dominance*.
- 6. What is abscission? What seems to control it?
- 7. What is a herbicide? How does 2,4-D work?
- 8. In what two ways is ethylene of great use to fruit producers?
- 9. What is the general effect of the gibberellins? How do they function in grass seeds?
- 10. What is the general effect of the cytokinins? How do they affect leaves?

MAIN IDEA

The gibberellins are growth stimulators, causing increased cell division and cell elongation.

MAIN IDEA

The cytokinins stimulate cell division and also seem to counter the effects of auxins.

ANSWERS TO CHECK YOUR FACTS

- 1. Hormones are chemicals produced by one tissue and transported to other tissues where they cause some kind of response. They regulate body activities.
- 2. The bending of a plant toward light.
- 3. They cause them to elongate.
- 4. Auxins move to the shaded side of the stem, causing cells on that side to elongate. This unequal growth rate causes the stem to bend.
- 5. Auxins from the apical meristems in the terminal buds have an inhibitory effect on the growth of lateral buds.
- 6. The falling off of leaves or fruit. A decrease in the amount of auxins.
- 7. A chemical that kills plants. It causes plants to grow too fast.
- 8. It can be used to control ripening and abscission.
- 9. They are growth stimulators. They cause other cells to synthesize enzymes.
- 10. They cause cells to divide. They keep leaves from aging.

Responses to the Environment

MAIN IDEA

Plants respond to their environment in a limited degree by various responses. These include the growth responses of phototropism, which is bending toward light, and geotropism, which is the growth response of the radicle toward the soil.

SCIENCE BACKGROUND

Growth itself is an ongoing response by plants. For plants such as vines that twist and weave and place their leaves always in the light, the growth response is even more dramatic.

23–8 Growth responses We know how animals respond to their environment. Most animals can respond by movements, toward something favorable or away from something that is unfavorable. Plants also respond to their environment. We have already mentioned how plants grow toward light, a response called phototropism. This is one type of plant response, which is caused by growth. Growth is slower than animal movements, but it is an effective response. The growth response to light enables plants to place their leaves in the sun and to avoid the shade.

Another type of growth response is the reaction of roots to gravity. The radicle of a young seedling will always grow downward, even when it is placed in different positions. This growth response is called a **geotropism** (jē ot'ra piz əm). The geotrophic response guarantees that roots will grow into the soil where there is moisture and essential minerals. It is as effective a response for a plant as is the response of an animal that sees a stream and walks to it for a drink of water.

The growth response of plant roots to gravity is called geotropism. The necessary moisture and minerals for these sweet potato roots are in the soil.



23-9 Photoperiodism Plants also respond to varying exposures to light and darkness. This kind of plant response is called **photoperiodism** (fō tō pir'ē ə diz əm), which means "time, or period, of light."

One type of photoperiodism is the flowering response. For example, ragweed will not produce flowers until the days are about 14.5 h long. Therefore ragweed will not grow at northern latitudes, because such short days do not occur until August. By that time it is too late for the seeds to mature before freezing temperatures kill the plants.

Another example is spinach, which will not grow near the equator. Spinach requires 14 h of light for a period of two weeks before it will flower. Fourteen-hour periods of daylight will never occur near the equator.

Plants are placed into three groups according to their flowering response to photoperiods. "Short-day plants" must be exposed to a photoperiod shorter than a specific time or they will not flower. Ragweed, strawberries, and chrysanthemums are examples of short-day plants. They, like other short-day plants, flower in the early spring or autumn.

The second group of plants are the "long-day plants." The long-day plants will only flower if the photoperiod is longer than a specific time. Spinach is an example of a long-day plant. It must have at least a 14 h photoperiod or it will not flower. Other long-day plants include lettuce and some kinds of potatoes.

The third group of plants will flower without a specific photoperiod. They are called "day-neutral plants."

Experiments have shown that it is the length of the dark period rather than the photoperiod that affects flowering in short-day plants. For example, the cocklebur requires a photoperiod of 16 h or less before it will flower. But in an experiment, researchers found that a 1 min exposure to a 25 W bulb during the dark period would prevent flowering.

Other experiments have shown how sensitive some plants are to the time of the photoperiod. For example, the long-day plant called henbane will flower if the photoperiods are as long as 10 h and 20 min (at 22.5°C). It will not flower if the photoperiods are only 10 h long.

23-10 Response to touch Several kinds of plants have mechanisms that allow them to respond when they are touched. One such plant is the sensitive plant *Mimosa pudica*. It has compound leaves, each with many leaflets. As soon as one of the leaflets is touched, most or all of the



Poinsettias and other plants can be made to flower at desired times of the year by artificially controlling the exposure time to light and darkness.

MAIN IDEA

Plants respond to varying periods of exposure to light or darkness. This response, called photoperiodism, is best illustrated by different flowering responses.

SCIENCE TERMS

geotropism
photoperiodism

SCIENCE BACKGROUND

The sudden movement of the leaflets in *Mimosa pudica* is the result of a change in turgor pressure at the base of the leaflets. But the exact mechanism is still unknown. The movement of the leaves of Venus's-flytrap also is the result of a sudden change in turgor pressure.

MAIN IDEA

Some plants can respond to touch. The advantage of that adaptation is obvious in a plant such as Venus's-flytrap but questionable in plants such as the sensitive plant.

ANSWERS TO CHECK YOUR FACTS

1. A response to gravity causing the radicle to grow downward. This ensures that the roots will grow into the most likely source of moisture.
2. The response of plants to light and darkness.
3. Plants that flower only if exposed to a photoperiod shorter than a specific time. Ragweed, strawberries, and chrysanthemums are examples.
4. Plants that flower only if exposed to a photoperiod longer than a specific time.
5. The length of continuous darkness.
6. When touched, the many leaflets of the compound leaves suddenly droop. This might scare off insects or discourage grazing animals.
7. Of the three sensitive hairs on a leaf, more than one must be stimulated or one must be touched several times before the trap is sprung. This prevents wasteful responses.

leaflets on one leaf will suddenly droop. Botanists are not certain how this adaptation helps the plant survive. One possibility is that the sudden drooping of the leaflets may discourage grazing animals from eating the plant. A plant with its leaflets drooping probably does not look very tasty. Another possibility is that the sudden reaction might scare off hungry insects when they land on the leaflets.

Another plant that responds to touch is Venus's-flytrap, which is a native of North Carolina. The leaves of this plant can fold in the middle as if they were hinged. When an insect lands or walks on a leaf, the leaf quickly folds up and traps the victim. There are glands in the leaves that secrete digestive enzymes. As the leaves press against the insect, it is digested by the enzymes. Then the nutrients are absorbed and used by the plants.

It is interesting that the Venus's-flytrap leaves will not fold up if touched by something falling on them, such as a small twig. There are three sensitive hairs on a leaf. In order for the triggering response to occur, two or three of them have to be touched, one after the other. Or, one hair has to be touched twice. The sensitive hairs are not likely to be touched in either way unless some living thing is moving over the surface of the leaf.

The modified leaves of the Venus's-flytrap respond to the touch of an insect by closing. In this way the plant obtains its dinner.



CHECK YOUR FACTS

1. Describe geotropism. How does it help the plant survive?
2. What is photoperiodism?
3. What are short-day plants? Give an example.
4. What are long-day plants?
5. What is the factor that determines whether a short-day plant will flower?
6. Describe the response to touch of *Mimosa pudica*. How might this benefit the plant?
7. How are the leaves of a Venus's-flytrap triggered? Why is this mechanism beneficial?

SUMMARY

Hormones are chemicals that regulate certain activities in organisms. They are produced, usually in very small quantities, in one tissue and are transported to other tissues where they cause some type of response. A major group of plant hormones includes the auxins. Auxins control phototropism by causing certain cells in the stem to elongate. The gibberellins are plant hormones that function as growth stimulators.

REVIEW QUESTIONS

1. What are hormones? Why might the quantity of a hormone be important to its function?
2. What are four ways that auxins are known to affect plants?
3. What is apical dominance? How can this effect be countered?
4. How is ethylene used by banana shippers? By orange growers?
5. How do the gibberellins affect plant cells? How do they affect dwarf plants?
6. Compare the actions of auxins and cytokinins on lateral buds.
7. List four types of plant responses. To what is each responding?
8. Why can't spinach grow near the equator?
9. Why won't ragweed, a short-day plant, survive in northern latitudes?

ANALYSIS AND APPLICATION

1. Would you expect a cocklebur plant to flower in the vicinity of a streetlight? Explain.
2. How is our knowledge of photoperiodism of economical value to florists?

ANSWERS TO REVIEW QUESTIONS

1. Chemicals produced in one tissue and transported to other tissues where they cause a response. The hormone might produce different effects depending on the amount.
2. (a) They cause phototropism. (b) They cause apical dominance. (c) They control abscission. (d) They induce excessive growth in some cases.
3. The inhibition of lateral bud development by auxins from the terminal bud. The effect can be countered by placing cytokinins on lateral buds.
4. Banana and orange shippers use ethylene to ripen the fruits at the most economically favorable time.
5. They cause cell elongation and cell division. The dwarf plants grow to normal size.
6. Normally auxins inhibit the growth of lateral buds. Cytokinins cause lateral bud growth.
7. (a) Phototropism—light. (b) Geotropism—gravity. (c) Photoperiodism—periods of light or darkness. (d) Response to touch.
8. Spinach requires a 14 h period of light to flower. This condition does not occur at the equator.
9. When the days become short enough to induce flowering, winter is too near to allow the plant time to reproduce.

ANSWERS TO ANALYSIS AND APPLICATION

1. No. The cocklebur requires an uninterrupted period of darkness to flower.
2. It ensures that the terminal bud will grow, thus increasing the height of the plant. The greater height will often make the plant a more successful competitor.

Investigations 39–40 from *Laboratory Investigations in Biology* can be done with this chapter.

24 *Transport*



OBJECTIVES

- To understand how the physical properties of cohesion and adhesion can be applied in the cohesion-tension theory
- To understand the nature of

the root system of plants

- To appreciate that most of the roots of a tree function to support the plant and do not absorb water
- To review the process of osmosis so that the mechanism of water flow into the root hairs will be understood
- To describe the functional relationship of osmosis, turgor, and the cell wall in keeping small plants upright
- To understand the mechanisms and limitations of the mass flow theory

in Plants

24-1 The transport functions Water moves up the stem from the roots to the leaves in every vascular plant. In addition, in every vascular plant, food moves downward from the leaves where it is manufactured to other cells that cannot make food. These two patterns of movement of water and food within vascular plants are called the transport functions. In this chapter we shall discuss both transport functions.

24-2 The nature of water The basic nature of water was discussed in Chapter 3. We shall review some of that material and introduce some new facts that will help you understand the water-transport mechanism in plants.

In Chapter 3 we explained that the water molecules are polar. They have regions with unlike poles. The unlike poles of the water molecules attract each other, creating a force within the water called **cohesion**. The poles of the water molecules often attract other substances. This attraction between two unlike substances is called **adhesion** (ad hē'zhən). Cohesion and adhesion are forces that operate in the transport of water in plants.

24-3 Transpiration In general, vascular plants take in much more water than they need. For example, an actively growing corn plant uses only about 2 percent of the water that it takes in through its roots. The other 98 percent is lost by **transpiration** (tran spə rā'shən). Transpiration is the loss of water mainly through the stomata, or pores, in the leaves. The water escapes from the leaves as water vapor, an invisible gas. As you will see,

MAIN IDEA

The transport functions include the movement of water from the roots to the leaves and the movement of food from the leaves to cells that cannot make food.

MAIN IDEA

Cohesion is the force that causes water molecules to be attracted to each other; adhesion is the force that attracts water molecules to other substances. Both forces operate in the transport of water in plants.

MAIN IDEA

Transpiration is the loss of water from a plant, which occurs mainly through the stomata.

SCIENCE BACKGROUND

Throughout the discussion of water movement in this chapter, we have ignored the nutrients that may be dissolved in the water—mainly mineral ions and soluble nitrates.

Water has condensed on the plastic covering around this plant as a result of transpiration through the stomata on the leaves.



MAIN IDEA

The cohesion-tension theory assumes that there are solid columns of water extending from the roots to the leaves in the xylem. Transpiration from the leaves creates a negative pressure that pulls the columns of water upward. Cohesion keeps the column together, while adhesion helps to keep it from settling.

SCIENCE BACKGROUND

Other names for the cohesion-tension theory are cohesion-adhesion-tension mechanisms and the transpiration-tension-cohesion theory.

transpiration is an essential process in the transport of water through the plant.

24-4 The cohesion-tension theory One of the mysteries of plant transport was how water could move from the roots to the top of tall plants such as trees. Several explanations have been proposed over the past years, but one, called the **cohesion-tension theory**, is now widely accepted.

According to the cohesion-tension theory, there is a solid column of water in the tubes in xylem tissue. This column of water extends from the leaves to the roots and is held together by cohesion—the attraction between water molecules. Adhesion also plays a role because the water is attracted to the cellulose walls of the leaf cells and to the walls of the xylem tubes. Adhesion helps keep the columns of water from settling.

Picture a very thin, tall column of water that stretches from the cells of a leaf all the way down through a xylem tube to the roots of a tree. Now picture what happens when some of the water is lost from the leaf by transpiration. The loss of the water creates a negative pressure in the leaf. This negative pressure is sometimes called “transpiration pull”. Transpiration pull exerts a force to pull the column of water up to replace that which is lost. In turn, this creates a negative pressure in the bottom of

the roots, which causes water to flow inward and become a part of the water column. Thus, as water is lost by transpiration there is a constant movement of the water column upward, and more water enters the roots from the soil. If transpiration is rapid, the movement of water upward through the plant will also be rapid. In some rapidly transpiring plants, the speed of the water movement may be as high as 40 m/h.

24-5 The root system and root hairs Most vascular plants have a large underground system of roots with many branches. Most of the root system functions to anchor the plant and to transport water toward the stem. It is mainly the younger roots—the new growth at the end of the roots—that actually absorb the water from the soil. For this reason, if you want to water a tree, place the sprinkler or hose away from the trunk and under the outside leaves. That is usually where new root growth is occurring.

In the new root growth some of the cells of the epidermis grow hairlike extensions. These hairlike extensions of the epidermal cells are called **root hairs**. Most water is absorbed through the root hairs. There are billions of root hairs on most root systems, which greatly increase the amount of surface area that is available for absorbing water.

24-6 The flow of water into the roots Why does water flow from the soil into the root hairs and not in the other direction? To answer this question, we must review the process of **osmosis**. Osmosis is the diffusion of water



Numerous root hairs on this radish root are clearly visible. Root hairs greatly increase the surface area available for water absorption.

MAIN IDEA (24-5)

Most of the root system functions only to anchor the plant and to transport water. Water absorption only occurs in the new growth through root hairs.

A properly watered plant (left) has turgor, resulting from the internal water pressure. Lack of water causes the plant to lose turgor and wilt (right).



SCIENCE BACKGROUND

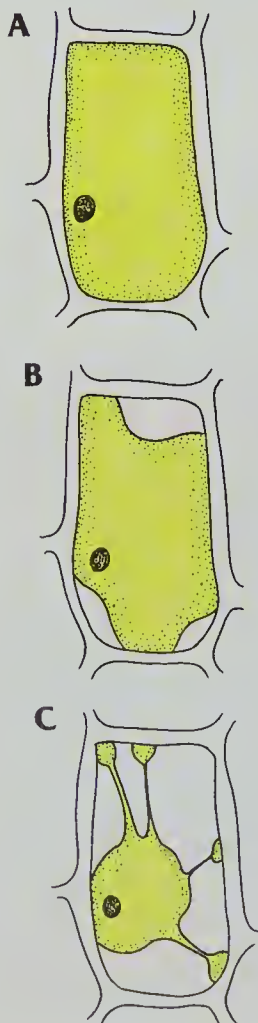
It is strongly recommended that *osmosis* be reviewed for all students.

MAIN IDEA (24-7)

Turgor keeps nonwoody plants erect. It results from the concentration gradient being normally toward the interior of cells. Cells do not break from turgor pressure because of the protective cell wall.

FIGURE 24-1

At the cellular level, insufficient water leads to plasmolysis. The plasma membrane shrinks away from the rigid cell wall.



through a semipermeable membrane, such as the plasma membrane that surrounds cells. The direction of osmosis depends upon the concentrations of water on each side of the membrane. Osmosis will occur along a concentration gradient from a high concentration of water to a lower concentration of water. Normally there is a greater concentration of water outside the root hair than on the inside. Therefore the concentration gradient is toward the inside of the root hair, and osmosis causes water to diffuse inward, from the soil to the inside of the root hair. From inside the root hair, the water continues to diffuse into the xylem where it will be transported upward.

The direction of osmosis may not always be toward the inside of the root hair. If some chemical, such as salt, is dissolved in water outside the root hair, the water concentration gradient develops in the opposite direction. If this occurs, osmosis will diffuse water outward, from the roots to the outside of the plant. This drains water from the plant and explains how placing salt on plants can kill them. It also explains why too much fertilizer may “burn” plants, or cause them to dry up and die. The fertilizer acts like a salt solution and reverses the normal direction of osmosis, causing the plants to lose their internal water.

24-7 Turgor and plasmolysis The concentration of water is always greater outside cells than inside them. Therefore the concentration gradient of water is normally toward the inside of the plant cell. Question: If the concentration gradient is always toward the inside of plant cells, why don't they swell up and explode like an over-filled balloon? Answer: They would if it were not for the rigid cell wall that surrounds them. The cell wall is like a protective box that keeps the plasma membrane from expanding and breaking.

The pressure of water that results from osmosis is called **turgor** (tér'gər). Turgor is the pressure that keeps small plants without woody tissue rigid and upright. A plant that is healthy has turgor; it stands erect and its leaves extend out in a horizontal direction. But turgor depends upon a vascular system that is full of water. If a plant does not take in enough water into its vascular system, it loses turgor. The stem and leaves then droop. We say that the plant and leaves *wilt*.

At the cellular level the loss of turgor is called **plasmolysis** (plaz mol'ə sis). During plasmolysis the cell actually shrinks like a balloon that is losing air. The shrinkage can be observed in the microscope as the plasma membrane shrinks away from the cell wall.



SCIENCE TERMS

cohesion
adhesion
transpiration
cohesion-tension theory
root hairs
osmosis
turgor
plasmolysis
guttation
translocation
mass flow theory

The droplets of water on the edges of these leaves were forced out of the plant as a result of high osmotic pressure in the roots. This process is called guttation.

24-8 Guttation Sometimes, usually during the night, the rate of transpiration from a plant will slow down quite drastically. But in small plants the osmotic pressure in the roots may continue to be quite high because of a steep concentration gradient. This pressure in the roots may become so great that in the upper part of the plant, water will be actually forced out through the tips and edges of the leaves. Such a process is called **guttation** (gu tǎ'shən). The water of guttation will often cling to the edges of the leaves. Since guttation normally occurs at night, the water on the leaves is often incorrectly identified as dew.

24-9 The transport of food Food moves through the phloem in leaves, stems, and roots of vascular plants. The food moves from cells that carry on photosynthesis to cells that cannot carry on that process. The food flows to active, living cells that require it, and the process is called **translocation** (trans lō kā'shən).

MAIN IDEA

Guttation may occur if transpiration slows down while osmotic pressure in the roots remains at its normal high level.

MAIN IDEA

Translocation moves food, which is mostly a water solution of sucrose, downward to cells that cannot carry on photosynthesis.

ANSWERS TO CHECK YOUR FACTS

1. The movement of water from the roots to the leaves. The movement of food downward from the leaves.
2. The evaporation, or loss, of water through the stomata.
3. Cohesion is the force of attraction among water molecules. Adhesion is the attraction of other substances to water molecules. In the xylem, cohesion keeps the water column continuous while adhesion between the water and the xylem tube walls helps keep the column from settling.
4. As water is lost from the leaves, the negative pressure that results pulls the water column upward.
5. Because the concentration of water is greater outside the root hairs. Osmosis.

MAIN IDEA

According to the mass flow theory, active transport brings sucrose into the phloem which, in turn, causes the concentration gradient of water to be from the cells that manufacture the food to the phloem. This osmotic pressure is enough to force the food solution through the phloem to the other cells.

ANSWERS TO REVIEW QUESTIONS

1. No. The old roots serve mainly to anchor the plant; the young roots absorb the water from the soil.
2. They are hairlike extensions of the epidermis. They increase the surface area available for water absorption.

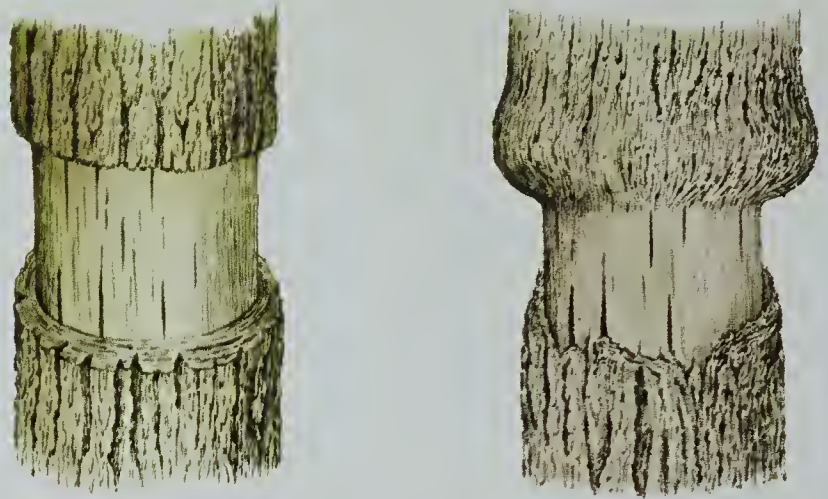


FIGURE 24-2 Removing the outer layers of tissue from a tree, including the phloem, is called girdling. The portion of the tree above the stripped area will grow for a time. The section below this area will quickly die.

The food that is translocated is mostly a water solution of sucrose, which is a disaccharide, or double sugar. But also in the solution are amino acids and other nitrogen compounds that are needed by cells.

24-10 How does translocation occur? Unlike water transport in plants, there is no single widely accepted theory to explain how translocation occurs. The best one at the moment—the one with the best experimental data to support it—is the **mass flow theory**.

According to the mass flow theory, the solution of food moves because of water pressure that is created near the cells that manufacture sugar. Here is a simplified explanation of how that pressure is created. Sugar that is manufactured during photosynthesis is moved from the cells that make it into the sieve tube cells, which make up the phloem. The sugar moves against a concentration gradient by active transport, a transport mechanism that requires energy. When the concentration of sugar is greater in the sieve tubes than in the surrounding cells, a concentration gradient of water develops toward the sieve tube. Therefore osmosis causes water to flow into the sieve tube, creating pressure that forces the sugar-water solution down through the phloem.

The rate of translocation is much slower than the rate of water transport. However, the rate of translocation is much faster than it could occur if mass flow were the only mechanism involved. For this reason many botanists are still looking for other mechanisms that may be involved in the translocation process.

CHECK YOUR FACTS

1. What are the two patterns of transport functions in plants?
2. What is transpiration? Where does most of it occur?
3. Distinguish between cohesion and adhesion. How do they work together in the xylem tissue?
4. How does the cohesion-tension theory explain water transport in plants?
5. Why does water move from the soil into the roots? By what process is this accomplished?

SUMMARY

Every vascular plant transports water upward from the roots and food downward from the photosynthetic cells of the leaves. These patterns of movement are called transport functions. The cohesion-tension theory explains how water is transported through the xylem against the force of gravity. The theory states that a continuous column of water between the roots and the leaves is maintained by cohesion and adhesion. Water loss in the leaves forces the column to rise, replacing the lost water and allowing more water to enter the roots.

REVIEW QUESTIONS

1. Do all roots absorb water? Explain.
2. Describe root hairs and their function.
3. Why doesn't the concentration gradient of water in plant cells cause the plasma membranes to burst?
4. What is turgor? What is needed to maintain it?
5. What is plasmolysis? How is it related to wilting?
6. What is guttation? Would you expect to find guttation and plasmolysis in the same plant? Explain.
7. Why does guttation normally occur at night?
8. What is translocation? What is transported?
9. According to the mass flow theory, what causes food to move?
10. Explain how the force in the question above is produced.

ANALYSIS AND APPLICATION

1. Why would pouring a salt solution in the soil surrounding a plant cause it to wilt and then die?
2. Which transport process would be affected by porcupines that often eat the bark and soft outer layers from the top of pine trees?

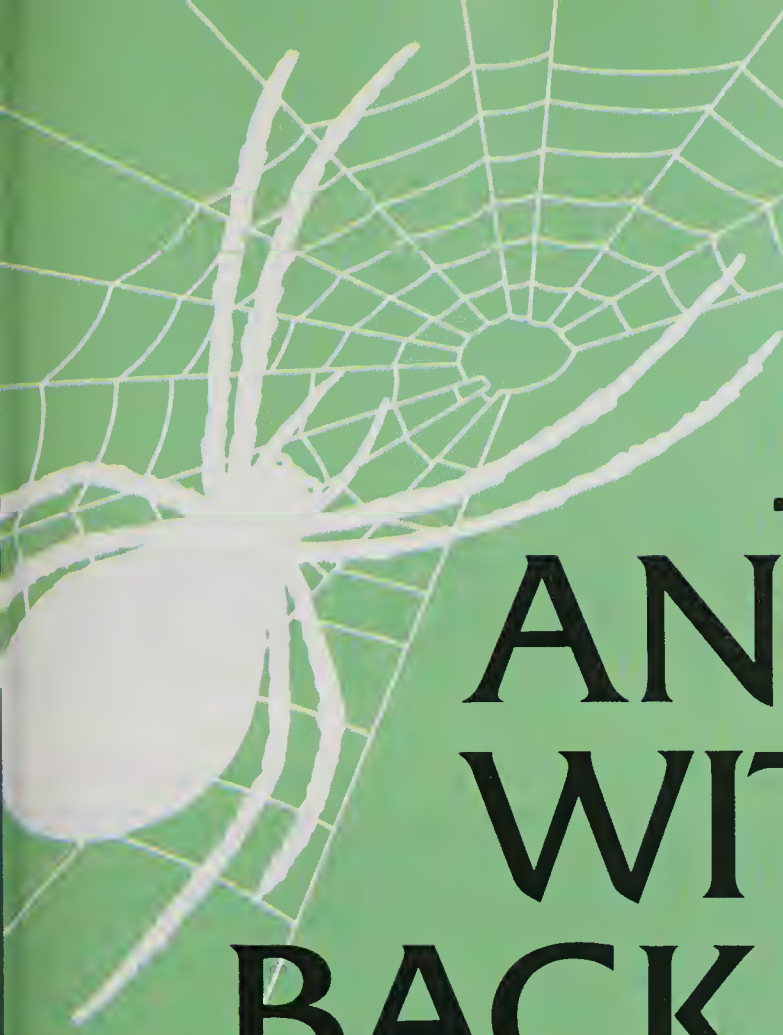
3. The rigid cell wall prevents bursting.
4. The water pressure resulting from osmosis in plants. A vascular system full of water.
5. The loss of turgor at the cellular level. Plasmolysis causes the plant to wilt.
6. The process by which water is forced out of the plant by pressure from within the plant. The two would not occur together since they are associated with opposite states of water pressure.
7. Transpiration is reduced at night. If the roots are still absorbing water, the reduced loss at the leaves will cause the water pressure in the plant to rise.
8. The process by which food is transported from the leaves to cells that cannot make their own food. The food is a water solution of sucrose with various amino acids and nitrogen compounds.
9. Water pressure that is created near the sugar-producing cells.
10. Sugar is actively transported into the sieve tubes surrounding the photosynthetic cells. The increase in sugar concentration causes a decrease in the water concentration in the sieve tubes. This causes pure water to flow into the sieve tube from surrounding cells, thus forcing the sugar-water solution down through the phloem.

ANSWERS TO ANALYSIS AND APPLICATION

1. The salt solution would reverse the concentration gradient. Osmosis would change the direction of water flow toward the outside of the plant.
2. Translocation.

UNIT 4 REVIEW

1. What are the general characteristics of bryophytes?
2. Discuss alternation of generations in a typical moss plant. Include a sketch of the moss life cycle.
3. Describe two additional methods of asexual reproduction found in moss plants.
4. Prepare a report on the dominant horsetails and lycopods from the Paleozoic Era.
5. During the spring and fall find several different kinds of ferns. Identify them using a field guide.
6. What is the difference between gymnosperms and angiosperms?
7. Many conifers are important to humans because of the products they supply. Prepare a report on the use of conifers by humans, including the most important types and the products produced from them.
8. Prepare a labeled diagram of the structures of a typical flower.
9. Discuss some of the methods used for seed dispersal. Why would adequate seed dispersal be advantageous for a plant species?
10. With your teacher's help, grow seeds of a particular species in several different media, such as soil and water. Prepare a report on the seeds' growth and the relative effectiveness of the media used in the experiment.
11. With the permission and supervision of your teacher, examine slides of roots and stems of various plants from the school's collection. Sketch the material and label all tissues that you can identify.
12. Explain the relationship between auxins and apical dominance.
13. The flowering response of many plants apparently depends on a particular length of darkness-time. Research the topic of photoperiodism and report on the most likely theory as to how the length of darkness-time affects flowering.
14. How does the cohesion-tension theory explain the upward flow of water in plants?
15. There are several different types of root systems in plants. Find out about the various types of root systems. Include in your report examples of plants having the various types of root systems.



Unit 5

ANIMALS WITHOUT BACKBONES

The invertebrate animals are those without vertebrae, or a backbone. This group includes animals with a variety of characteristics. Some, like the sponges, are not much more than groups of independent cells stuck together in a mass. Others, like the giant squid, have a body far larger than a human and an eye that almost rivals our own. But it is in numbers that the invertebrates reign supreme. There are far more different kinds of invertebrates than there are of all the other animals and plants put together.

25

The Simplest



Animals

OBJECTIVES

- To describe four general characteristics of animals
- To understand the terminology relating to animal structure
- To understand the basic structural and functional characteristics of the sponge
- To appreciate the basic structural and functional characteristics of coelenterates
- To realize that sponges and coelenterates are aquatic organisms

Introduction to the Study of Animals

25-1 Characteristics of animals Animals have at least four characteristics that make them different from other organisms. One major difference can be observed inside the animal body. The cells that make up the animal body do not have a cell wall of cellulose like that found around plant cells and the cells of many protists. In most animal cells the plasma membrane is exposed directly to the outside environment.

A second unique characteristic of most animals is that they reach a stage called adulthood. At this time they stop growing. Plants, on the other hand, continue to grow throughout most of their lifetime.

A third major characteristic of animals is an ability called **locomotion** (lō kə mō'shən). Locomotion is the ability most animals have to move from one place to another. Animal locomotion is made possible by special muscle cells that have the ability to contract, or get smaller. Animals that are capable of locomotion can react to their environment by swimming, running, or even flying. The rooted plant must remain and take what the environment offers.

A fourth major characteristic of animals is their dependency on other organisms for food. Animals cannot make their food as plants and many protists can. Most animals eat plants or other animals.

25-2 Kinds of animals The study of animals is the science called **zoology** (zō ol'ə jē). Scientists who study animals are called **zoologists** (zō ol'ə jists). One

MAIN IDEA

Animals have no cell walls, reach adulthood, have locomotion, and must feed on other organisms.

SCIENCE BACKGROUND

Some animal cells, such as those that line the stomach and intestines, are protected by a coating of thick fluid called mucus. Others secrete chitin for structural rigidity that duplicates the role of the cellulose in plant cells.

MAIN IDEA

Zoologists study animals. About 1 100 000 kinds of animals have been classified in kingdom Animalia. Most animals are contained in the nine phyla that will be discussed.

SCIENCE TERMS

locomotion
zoology
zoologists
kingdom
kingdom Animalia
phylum
symmetry
radial symmetry
bilateral symmetry
anterior
posterior
dorsal
ventral
medial
lateral
appendages
distal
proximal

SCIENCE BACKGROUND

The nine phyla to be studied in this text and the approximate number of species in each are as follows:

1. Porifera—4 500
2. Coelenterata—9 000
3. Platyhelminthes—15 000
4. Aschelminthes—11 875
5. Mollusca—100 000
6. Annelida—7 000
7. Arthropoda—923 000
8. Echinodermata—5 700
9. Chordata—41 210

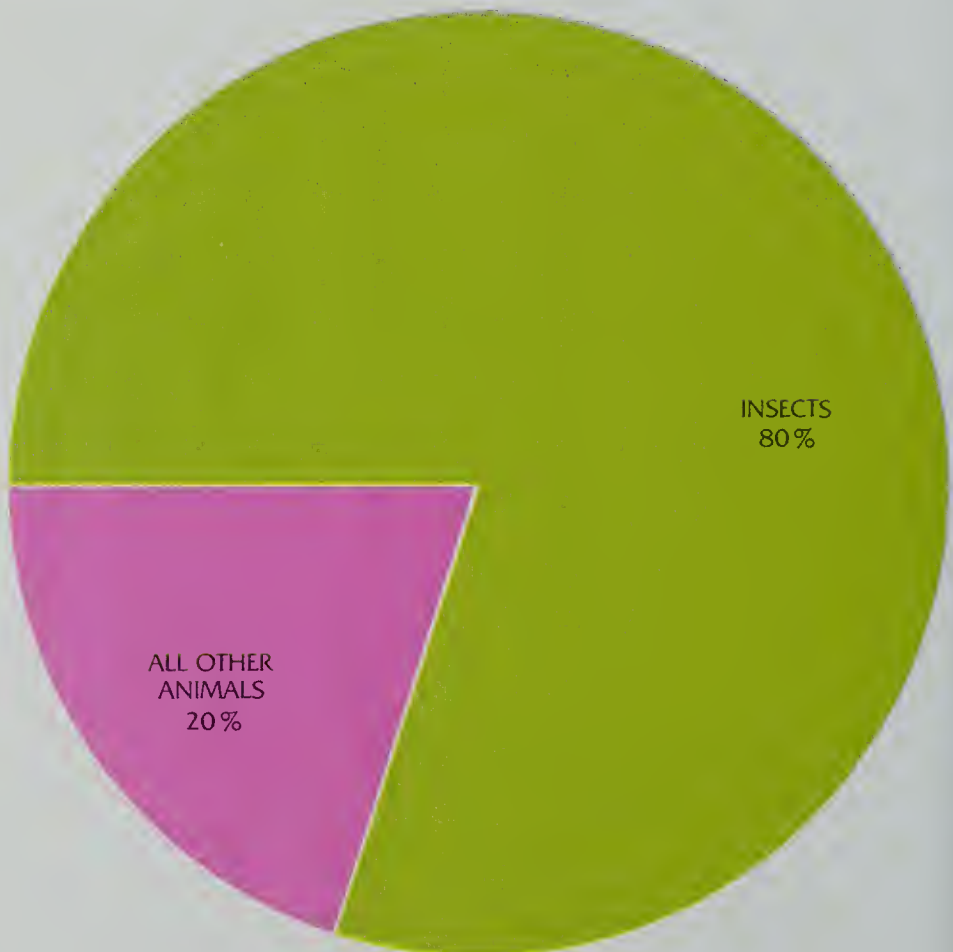
important job of the zoologist is to discover and identify all the different kinds of animals that live on the earth. That task is still incomplete. Also there is no single library or museum catalog that has a record of all the animals that have been discovered and named. Therefore zoologists can only estimate that about 1 100 000 different kinds of animals have been found and identified. Of these 1 100 000 animals, about 80 percent—or 8 out of every 10—are insects.

Another job of the zoologist is to classify animals and organize them into groups. The largest group is called the **kingdom** and includes all the animals. The correct name for this group is **kingdom Animalia**.

The next group below the level of the kingdom is called the **phylum** (pl. *phyla*). Many zoologists group the animals in kingdom Animalia into 27 different phyla. However, only 9 of the animal phyla are really important in an introductory study of animals. The 9 phyla that will be discussed in this chapter and in others that follow contain about 99 percent of all the different animals.

FIGURE 25-1

Approximately 80 percent of all the known species of animals are insects.



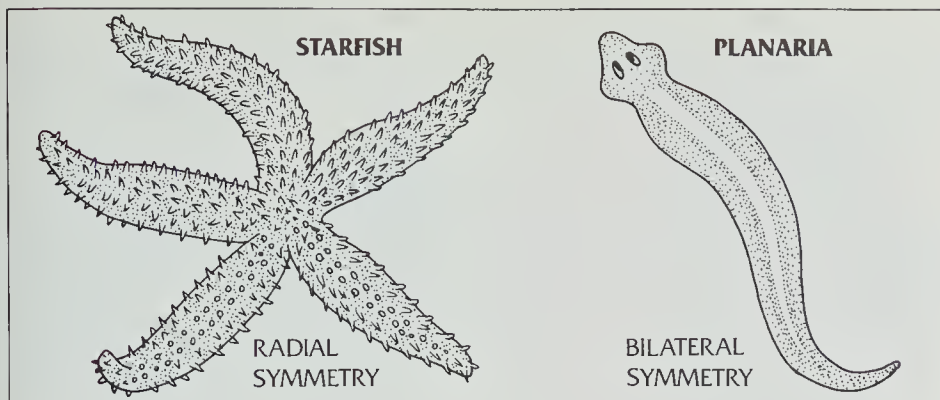


FIGURE 25-2

A starfish has radial symmetry. A flatworm, such as a planarian, has bilateral symmetry. What type of symmetry do humans have?

25-3 Symmetry and the animal body Most animal bodies have **symmetry** (sim'ə trē), which means that a cut along a central plane would divide the body into two equal halves. However, there are two types of symmetry, and an animal will have one or the other.

One type of symmetry is called **radial** (rā'dē əl) **symmetry**. An animal with radial symmetry has the same symmetry as a pie. A cut anywhere through the middle of a pie results in two equal halves. A cut anywhere through the middle of an animal with radial symmetry would result in an animal divided into two equal halves. Animals with radial symmetry are often attached to one place in their environment. An example is the sea anemone.

Most animals have a type of symmetry called **bilateral** (bī'lat ər əl) **symmetry**. To obtain two equal halves of an animal with bilateral symmetry, the cut could be made in only one place. The flatworm is an example of an animal with bilateral symmetry.

Animals with bilateral symmetry usually have a concentration of nerve tissue at one end of their body. This is the front, or head end, which must meet and respond to challenges of the environment.

25-4 Terms to describe regions of the animal body Zoologists use specific terms to describe different regions of the animal body. For example, the head end, or front end, of the animal body is called the **anterior** (an tir'ē ər) region. The opposite end, or tail end, is called the **posterior** (pos tir'ē ər) region.

The top of an animal is called the **dorsal** (dôr'səl) region. The belly, or underside, is called the **ventral** (ven'trəl) region.

The midline of the animal body, which is the line that would divide the animal into two equal halves, is the **medial** (mē'dē əl) region. The sides of the animal body are called the **lateral** (lat'ər əl) regions.

MAIN IDEA

Animals with radial symmetry yield equal halves with any cut through their center. Animals with bilateral symmetry can only be cut in one place to yield equal halves. Nerve tissue usually concentrates in the front end of these animals.

SCIENCE BACKGROUND

The terms describing different body regions apply mostly to the majority of animals with bilateral symmetry.

MAIN IDEA

Anterior and *posterior* refer to head and tail regions. *Dorsal* and *ventral* refer to top and bottom. *Medial* and *lateral* refer to the middle and the sides of an organism. Appendages are extensions. *Distal* and *proximal* describe distance from a reference point.

ANSWERS TO CHECK YOUR FACTS

1. They lack a cell wall; they reach adulthood, a point at which they stop growing; they have the ability of locomotion; and they must eat other organisms for food.
2. Scientists who study animals.
3. About 1 100 000.
4. The phylum. Twenty-seven.
5. An animal with radial symmetry can be cut along any central plane to yield two equal halves.
6. An animal with bilateral symmetry can only be cut in one place by a central plane to yield two halves.

MAIN IDEA

Sponges are sessile aquatic invertebrates.

Pores are clearly visible in this photograph of a crimson sponge. The pores permit water, carrying food and oxygen, to reach all body cells.

Most animal bodies have parts that extend outward from the main body—parts such as tentacles, wings, fins, or legs. Such extensions of the animal body are called **appendages** (ə pen'di jz).

Two other terms are often used to describe the relative distance of some body structure from a reference point. **Distal** (dis'təl) is used to describe a region that is farther from a reference point. **Proximal** (prok'sə məl) is used to describe a region that is closer to a reference point. For example, your fingers are more distal from your body than your elbow is. Or, saying it another way, your elbow is more proximal to your body than your fingers are.

CHECK YOUR FACTS

1. Name four major differences between animals and other forms of life.
2. What are zoologists?
3. How many kinds of animals are known?
4. What is the next subunit below the kingdom? How many of these does kingdom Animalia contain?
5. What is radial symmetry?
6. What is bilateral symmetry?

Phylum Porifera

25–5 General characteristics All members of the phylum Porifera are called sponges. Sponges are strictly aquatic animals. Most of them live in marine waters. Only a few kinds live in freshwater ponds, lakes, and streams.

The sponges are called **invertebrate** (in vér'tə brit) animals because they do not have a backbone. More than 99 percent of all animals are invertebrates.





FIGURE 25-3

The general body plan of a typical sponge is illustrated in this figure.

All sponges are **sessile** (ses'əl) animals, which means that they are permanently attached in one place. For many years sponges were thought to be plants because of this characteristic. In marine waters sponges are found in both shallow and deep water. Usually they are attached to rocks and other solid objects. Many are brown or gray in color, but some are bright orange or red. Freshwater sponges are usually found attached to underwater sticks and logs. Freshwater sponges often have a green color caused by algae growing inside their body. The algae probably contribute food to the cells of the sponge.

25-6 General body structure A sponge has the simplest body structure of all the animals. It has no systems, organs, or tissues. However, some cell groups function somewhat like teams. Zoologists consider such cell groups as the probable forerunners of tissues, which are found in all other animals.

The phylum name *Porifera* means “pore-bearing animal.” That is a good name because the body of a sponge is full of holes, or pores. The pores are linked to canals, and the canals form a network throughout the sponge. Water constantly circulates throughout the canals in the sponge body. The water carries food and oxygen to the body cells and waste materials away from them.

Sponges have various shapes. Some have radial symmetry and look like flower vases. Others are irregularly shaped, and some have branches that extend from their body. Some sponges grow singly, but others form colonies. A **colony** (kol'ə nē) is a group of individuals that are

MAIN IDEA

Sponges have no tissues. Water circulates through canals. Some have radial symmetry. Some form colonies. Amoebocytes manufacture the sponge skeleton.

SCIENCE BACKGROUND

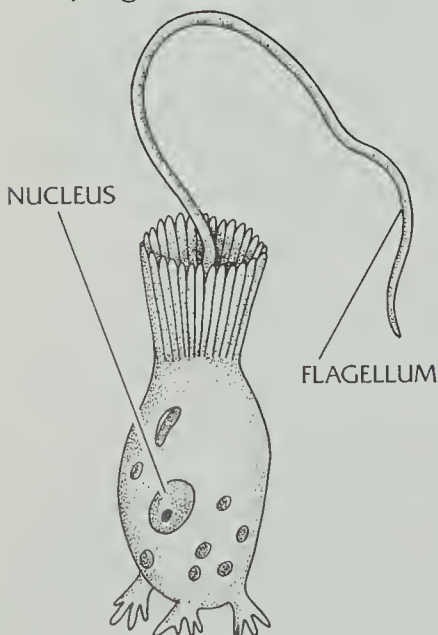
Sponges are classified into three classes based on their type of skeleton. The *Calcispongiae* have a skeleton of calcium carbonate spicules. The *Hexactinellida* have a skeleton of six-rayed siliceous spicules. The *Demospongiae* have a skeleton of spongin or of siliceous spicules that do not have six rays.

MAIN IDEA

Calcium carbonate, silica, and spongin are materials found in sponge skeletons. Many skeletons have protective spicules.

FIGURE 25-4

The whiplike activity of the flagella of numerous collar cells sets up a strong current that draws water through the body of the sponge.



either attached to each other or are growing very close together.

The body of a sponge consists of three layers. The outer layer is made up of flattened cells that form a lining over the outside surface. The innermost layer forms a lining of pores, canals, and other cavities inside the body. The middle layer of the sponge contains a gelatinlike material and wandering cells that are amoebalike and are called **amoebocytes** (ə mē'bə sītz). One function of the amoebocytes is to manufacture the sponge skeleton. The skeleton provides support inside the sponge body.

25-7 The sponge skeleton There are three types of skeletal materials that are found in sponges. One material is calcium carbonate, which is a chalklike material such as that found in the shells of snails and clams. The calcium carbonate is formed into small, sharp spikes called **spicules** (spik'yŭlz). The second type of skeletal materials is **silica** (sil'ə kə), a glasslike substance. The silica also is formed into sharp spicules. Many sponges with spicule skeletons have the sharp points of the spicules sticking out from their body. The sharp spicules help protect the animals from predators.

The third type of skeletal material is a protein fibrous material called **spongin** (spun'jin). The true "bath sponge" that is used for cleaning purposes is a spongin skeleton. In the preparation of bath sponges the live animals are beaten to break up the cell masses, then left in shallow water for the cells to decompose. Then they are bleached and washed, leaving the spongin skeleton with its millions of holes and canals that can soak up large amounts of water.

25-8 Feeding and digestion The sponge is a **filter feeder** (fil'tər fē'dər), which is an animal that filters small particles of food out of the water that passes through its body. Like most filter feeders, the sponge has a way of greatly increasing the flow of water through its body. The sponge creates currents with special cells, called **collar cells**, that line the interior of its body.

Each collar cell has a flagellum that whips back and forth and creates a whirlpoollike current. The combined action of all the collar cells in the sponge creates a strong current that draws water through the sponge body.

The actual collar of the collar cell is made up of a number of fingerlike extensions. Together those fingerlike extensions act like a funnel. Small food particles, such as bacteria, are funneled down inside the collar by the whirlpool

created by the flagellum. There they catch on the inside, sticky surface of the collar. Then the food particles are engulfed into a food vacuole in the same way that an amoeba takes in food.

Digestion of the food may occur in the main body of the collar cells. Another possibility is that the food particles will be transferred to the amoebocytes that wander around in the middle layer of the sponge body. The amoebocytes digest the food and may carry the nutrients to other cells in the body.

25-9 Gas exchange All animals must have some way of obtaining oxygen from the environment outside the body. Also all animals must have a way of releasing carbon dioxide and other gaseous wastes from the interior body cells to the exterior environment. The process by which oxygen is obtained from outside the body and gaseous wastes are released is called **gas exchange** (eks chānj').

Gas exchange in the sponge is a simple process. Oxygen is dissolved in the water that flows through the sponge body. From the water the oxygen diffuses directly into the cells that line the canals and cavities of the body. From these cells the oxygen diffuses into the other cells in the sponge body. The loss of gaseous wastes occurs in the opposite manner. Carbon dioxide and other wastes diffuse to the cells lining the canals and cavities, and from these into the current of water.

25-10 Coordination Another problem for most animals is the coordination of all parts of the body so that they work together. In most animals this task is performed mainly by nerve tissue made up of specialized nerve cells. But not in the sponge. Sponges have no specialized nerve cells. However, some cells, such as those lining the outside pores, have the ability to respond by contracting when they are touched. This is apparently a response by individual cells, rather than a coordinated response of a cell group.

25-11 Reproduction Sponges can reproduce by three asexual methods and by one sexual method. One asexual method is by **regeneration** (ri jen ə rā'shən). If you break a sponge in several pieces, each piece will regenerate a new sponge. Years ago a zoologist even strained cells through cloth and found that groups of cells that had received this treatment still regenerated into new sponges. The method of regeneration is used in the bath sponge industry. Sponges of the type that produce com-

MAIN IDEA

Sponges are filter feeders. Collar cells increase the flow of water through the body. Digestion occurs in the collar cells or in the amoebocytes.

MAIN IDEA

Gas exchange is by diffusion from the water to the lining cells to the body.

SCIENCE BACKGROUND

Many different animals live in natural cavities of the sponge or burrow into the sponge and make cavities of their own. Such animals include sea anemones, polychaetes (annelids), octopuses, copepods, barnacles, amphipods, shrimp, brittle stars, and fish.

MAIN IDEA

Sponges have no nerve cells but some areas can respond to touch.

MAIN IDEA

Sponges can reproduce by regeneration, budding, gemmules, or sexual reproduction.

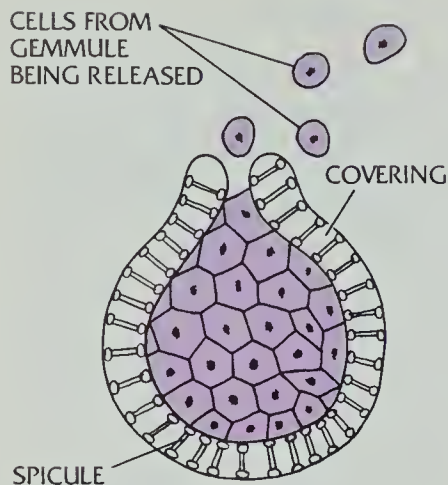


FIGURE 25-5

Gemmules can withstand cold temperatures and drying. When favorable conditions return, cells are released and these develop into new sponges.

SCIENCE TERMS

invertebrate
sessile
amoebocytes
spicules
silica
spongin
filter feeder
collar cells
gas exchange
regeneration
budding
gemmule
habitat

mercial bath sponges are cut into many small pieces and “seeded” in favorable growing areas. After several years the offspring are then harvested.

A second method of asexual reproduction is by **budding** (bud'ing). In this process a small extension, or bud, begins to grow from the side of the sponge body. When the bud reaches a certain size, it breaks off and develops into a new sponge.

A third method of asexual reproduction is used by freshwater sponges and by some marine species. A small structure called a **gemmule** (jem'yul) is formed within the body of the sponge and then released into the water. The freshwater sponge may die during the winter, but the gemmule can withstand cold and also drying, should the water dry up. Later, when conditions are favorable, the cells in the gemmule are released. Then they divide and produce another sponge.

The fourth method of reproduction is by sexual reproduction, which varies among different sponges. Generally sponges produce both sperm cells and egg cells. The sperm cells are released into the water, where they are capable of swimming with a flagellum. The egg cells may be produced in the middle layer of the sponge. For reproduction to occur, a sperm must be trapped and absorbed from the water by a collar cell. When trapped, the sperm cell loses its flagellum. Also, the collar cell withdraws its collar and flagellum, then becomes a carrier cell that transports

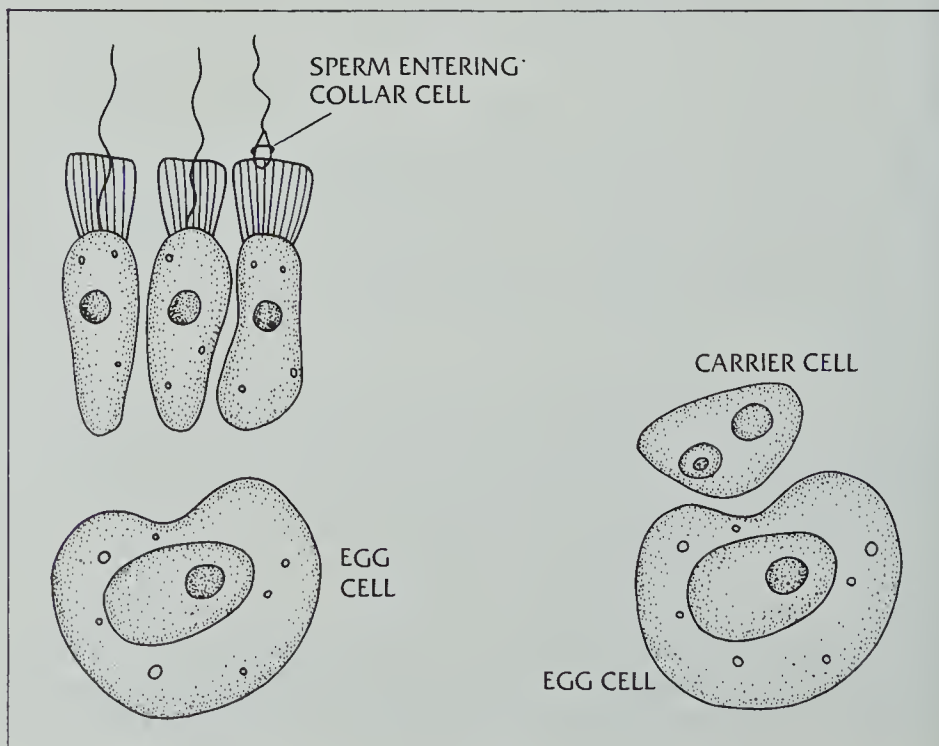


FIGURE 25-6

Sexual reproduction in sponges involves the trapping of a sperm cell by a collar cell. The collar cell becomes a carrier cell.

the sperm cell to the egg cell. After fertilization, cell division begins and the cell mass develops into a small multicellular larva, which swims out of the sponge. Eventually the larva settles on a solid surface and begins to develop into another adult sponge.

25-12 Environmental relationships All animals have different relationships with other organisms in their environment. Many sponges have a unique relationship. They serve as a **habitat** (hab'ə tat), or home, for smaller animals. The hollow spaces inside their body make an ideal habitat for a number of different small animals. For example, one zoologist collected a large loggerhead sponge and counted 16 000 small shrimp inside its body.

CHECK YOUR FACTS

1. What are invertebrates? Are most animals invertebrates?
2. What is a sessile animal?
3. Do sponges have tissues? Organs?
4. How is oxygen circulated to the cells of the sponge?
5. Where are amoebocytes located? What is their function?
6. Name the three types of skeletal material found in sponge skeletons.
7. Explain how collar cells function in digestion.

ANSWERS TO CHECK YOUR FACTS

1. Animals without a backbone. Yes.
2. An animal that is attached in one place.
3. No. No.
4. It is contained in the water that circulates through the canal network of the sponge. Oxygen diffuses into the cells lining the canals.
5. In the middle layer of the sponge. They manufacture the sponge skeleton.
6. Calcium carbonate, silica, and spongin.
7. Each collar cell has a flagellum that helps draw water into the sponge. Extensions on the collar cells trap food particles carried by the water entering the sponge.

Phylum Coelenterata

25-13 Introduction There are about 10 000 different species of animals that belong to the phylum Coelenterata. All these animals are aquatic. Practically all of them live in marine waters.

The coelenterates include such marine animals as the jellyfish, Portuguese man-of-war, sea anemone, and coral. Also belonging to the phylum Coelenterata is a small animal called the hydra, which lives in freshwater ponds, lakes, and streams.

25-14 General body structure The coelenterates have four general body characteristics that are different from most other animals. First, their body has radial symmetry, a characteristic that only one other major phylum of animals (phylum Echinodermata, which includes the starfish and sea urchin) has.

The second characteristic of coelenterates is an interior body cavity with a single opening, which serves both as a mouth and as an exit for body wastes.

MAIN IDEA

The coelenterates include about 10 000 species. All are aquatic. Most are marine.

MAIN IDEA

Coelenterates are characterized by radial symmetry, a single opening in the body cavity, a two-layered body, and the presence of cnidoblasts.

SCIENCE BACKGROUND

Coelenterata is from the Greek words *koilos*, which means "hollow," and *enteron*, which means "gut." Another name for the phylum is *Cnidaria*, which originates from the Greek word *knide*, meaning "nettle," or something that stings.

MAIN IDEA

Hydra has a polyp form. The gastrodermis lines the gastrovascular cavity. Mesoglea lies between the two body layers. The basal disc anchors the hydra. Hydroids can glide, somersault, or crawl.

SCIENCE BACKGROUND

The algae in the green hydra are indistinguishable from the common unicelled alga *Chlorella*.

Many coelenterates have both the polyp- and medusa-form bodies during their life cycle, an example of polymorphism, which allows the exploitation of two different niches and undoubtedly contributes to the continued success of these organisms. Polymorphism and the successful utilization of two niches achieves its highest efficiency with the insects.

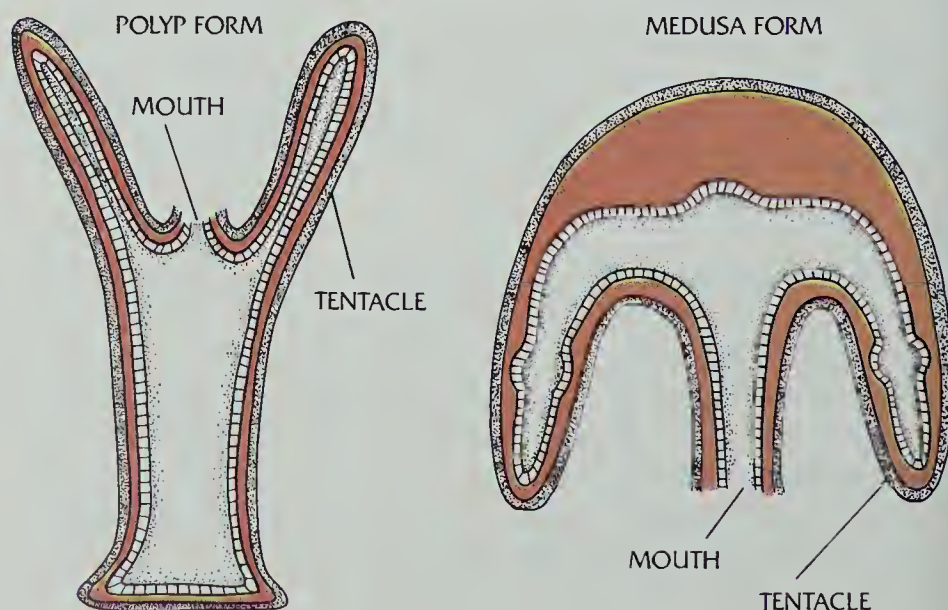
The third characteristic is a body made up of two layers of cells: an outside layer and an inside layer. Between the two layers of cells is a noncellular, jellylike substance called **mesoglea** (mes ə glē'ə).

The fourth characteristic of coelenterates is the presence of highly specialized cells called **cnidoblasts** (nī'də blasts). Each cnidoblast contains a **nematocyst** (nem'ə tə sist), which is a capsule with a coiled thread that can be shot out and used to capture small animals for food. Most coelenterates have one or more rows of tentacles surrounding their mouth. The cnidoblasts containing nematocysts are concentrated in those tentacles. When a small animal suitable for food comes close, the nematocysts shoot out a thread that poisons or entangles the small animal. At the same time the tentacles grasp the victim and pull it into the mouth.

25-15 The hydra The hydra is the best known and most widely studied coelenterate (class Hydrozoa). It is found in bodies of freshwater throughout the world, usually attached to leaves, stones, and sticks. It is a small animal, often less than 1 cm long. But it is capable of stretching, and some have been measured as long as 3 cm. A typical place to see hydroids is the underside of a floating lily pad from a pond. The most common hydra is the green hydra, which gets its color from green algae cells that live in the hydra's cells. Another common hydra is the brown hydra.

FIGURE 25-7

The polyp body form, typified by the hydra, is shown on the left. The medusa body form, found in the jellyfish, is shown on the right.



The coelenterates have two body forms. The hydra illustrates the body form called a **polyp** (pol'ip). The polyp has its mouth and tentacles facing upward. The other body form is the **medusa** (mə dü'sə), which has its mouth and tentacles facing downward. The jellyfish is an example of a coelenterate with a medusa-form body.

The hydra polyp is a good example to illustrate the structure and function of the coelenterate body. Two layers of cells make up the polyp body wall. The outer layer of cells, the **epidermis**, is made up mostly of cells with two functions. One function of the epidermal cells is to protect the rest of the body. Their second function is movement. At the base of the epidermal cells there are muscle fibers running lengthwise with the cell. Contraction of these fibers allows the hydra to shorten or bend its body.

The inside layer of cells is called the **gastrodermis** (gas trō dēr'mis). The gastrodermis lines the body cavity, which is called the **gastrovascular** (gas trō vas'kyə lər) **cavity**. The cells of the gastrodermis have several functions. They protect the inside body cavity. They also have muscle fibers in them that create movement in opposite directions from those in the epidermis. When the muscle fibers of the gastrodermis contract, they constrict the body, making it thinner and longer. Also, the cells of the gastrodermis function in digestion, which will be discussed shortly.

Between the two cell layers in the coelenterate body there is a noncellular layer, the mesoglea. In some coelenterates there may be a few cells scattered through the mesoglea, but mostly it is made up of a thick, jellylike substance. In polyp-form coelenterates like the hydra, the mesoglea is quite a thin layer. However, in medusa-form coelenterates, the mesoglea is thicker than either of the two layers of cells. In medusa-form coelenterates the mesoglea accounts for most of the animal's body volume.

At the base of the hydra is a special group of cells called the **basal** (bā'səl) **disc**. The cells of the basal disc produce a sticky substance that allows the hydra to remain attached to solid objects, even in currents of water. Also the cells in the basal disc are capable of slow movement, much like the movement of an amoeba. These cells enable the hydra to glide slowly across the solid surface to which it is attached.

The hydra can move more rapidly by two other methods. One is by somersaulting. By this method the hydra bends over, touches its tentacles to the surface, and releases its basal disc. Then it turns over, attaches the basal disc, and stands upright. The second method resembles the

SCIENCE BACKGROUND

Seventeen types of nematocysts have been identified, but they belong in the three general categories described in the text.

The nematocyst is often described as being like a balloon with a long thin neck that has been everted and coiled within the body of the balloon. When the nematocyst discharges, pressure (probably hydrostatic) forces the thin neck (the hollow thread) to pop out. The effect is much like blowing the fingers out of a rubber glove that has been turned inside out.

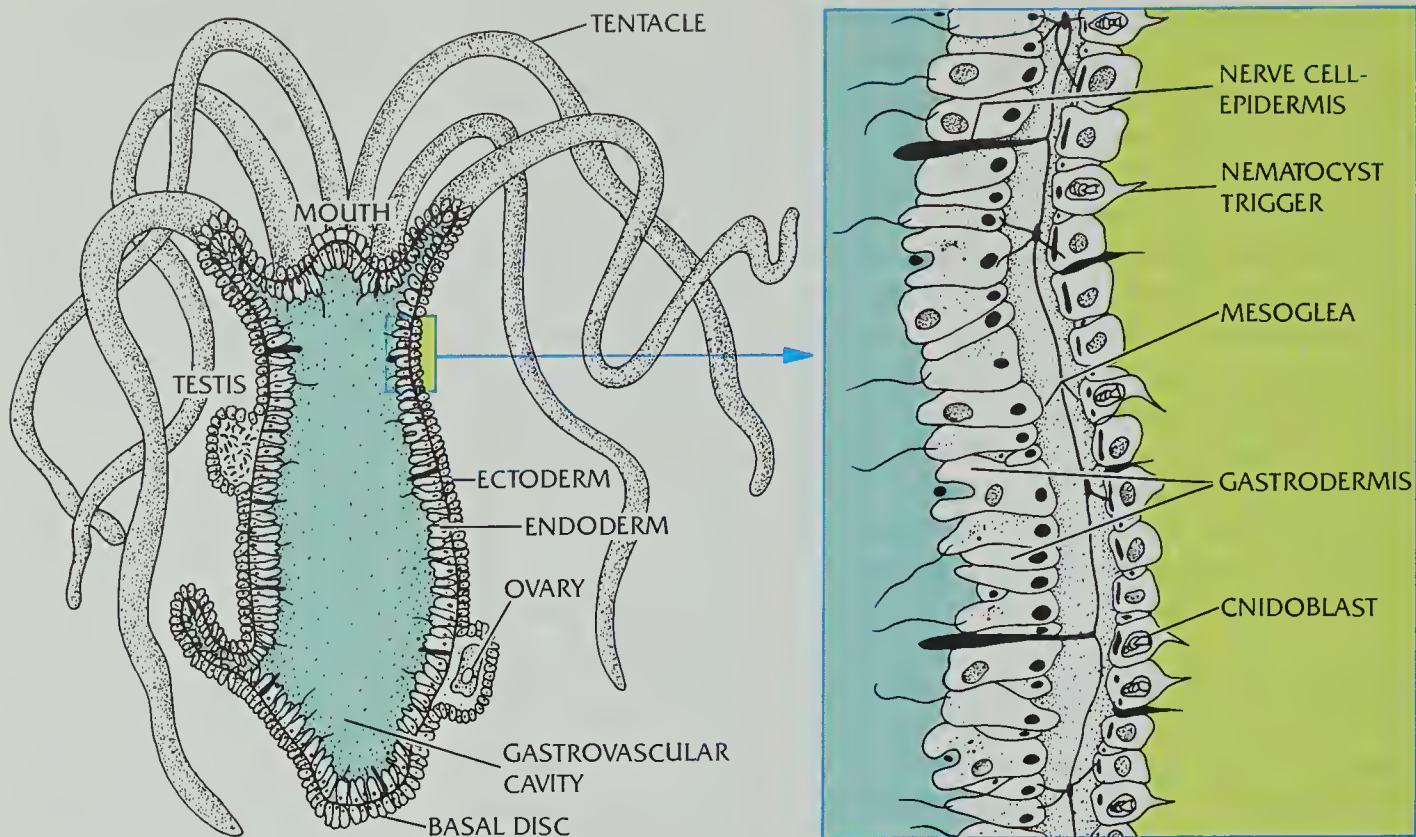


FIGURE 25-8

The structure and the body form of a hydra are shown in the illustration above.

MAIN IDEA

Chemical and mechanical stimuli cause the nematocyst to discharge. After lodging in the prey, poison travels through the hollow thread. Other nematocysts function by slowing or trapping the prey.

movement of a measuring worm, a caterpillar that moves along with a hump in its body. The hydra leans over and attaches its tentacles, slides the basal disc towards the tentacles, then stands upright.

25-16 Feeding and nematocysts The hydra has several long tentacles with cnidoblasts grouped together in clusters. When a small animal suitable for eating comes near the cnidoblasts, the nematocysts, which are inside, shoot out their coiled threads. Each thread is hollow and sharp-pointed. It penetrates the body of the animal, and poison from inside the nematocyst travels through the hollow thread, into the body of the prey. The poison partly or wholly paralyzes the prey, so that the tentacles can complete the work of capturing it and pulling it into the mouth.

What is it that causes the nematocysts to discharge? Just touching the tentacles with a clean needle in the laboratory usually will not cause them to discharge. The presence of certain chemicals, such as are found in small organisms that the hydra feeds upon, is also required. Actually it is a combination of two stimulants that causes the nematocysts to discharge. First, the hydra “tastes” the proper chemicals given off by the likely prey. Second, the prey touches a triggerlike device that extends a short dis-

tance from the cnidoblast. Together both stimulations, chemical and touch, cause the nematocysts to discharge. Once a nematocyst has discharged, it cannot be used again.

There are three basic kinds of nematocysts found in coelenterates. Many are like those in the hydra, with sharp points and a poison that paralyzes the prey. Another type of nematocyst is a long thread that coils around the prey and traps it like a cowhand's lasso. A third type has a sticky substance on the thread that slows down the prey, so that the tentacles can complete the capture.

It is interesting that some flatworms and a marine animal called a sea slug can use the nematocysts of coelenterates that they have eaten. Somehow the nematocysts pass through the digestive system of these animals without being digested and without getting discharged. From the digestive system they pass to the epidermis of the animals, where they help in defense against predators.

25-17 Digestion, transport, and gas exchange The mouth and gastrovascular cavity can expand to many times their normal size. Therefore hydras and other coelenterates can eat animals larger than themselves.

After the captured animal is inside the gastrovascular cavity, digestion begins in the first of two stages. In the first stage certain cells in the gastrodermis begin producing and releasing **digestive enzymes** into the gastrovascular cavity. Digestive enzymes are chemicals that break down food into nutrients that can be used by the animal's own cells. The first stage of digestion is called **extracellular** (eks trə sel'yə lər) **digestion** because it occurs outside the cells of the gastrodermis, in the gastrovascular cavity.

The second stage of digestion occurs inside certain cells of the gastrodermis and is called **intracellular** (in trə sel'yə lər) **digestion**. Intracellular digestion occurs after certain cells of the gastrodermis surround and engulf partly digested food particles. This is the process of phagocytosis that was discussed in Chapter 2. Inside the cell the food particles are enclosed in a food vacuole. Digestive enzymes are released into the food vacuole. They complete the digestion. Essential nutrients then diffuse from the food vacuole, while undigested wastes are released by exocytosis.

The nutrients are then transported to all the other cells in the coelenterate body by diffusion. There is no transport system as is found in more complex animals.

Gas exchange also occurs by diffusion. Solid waste materials are eliminated from the gastrovascular cavity through

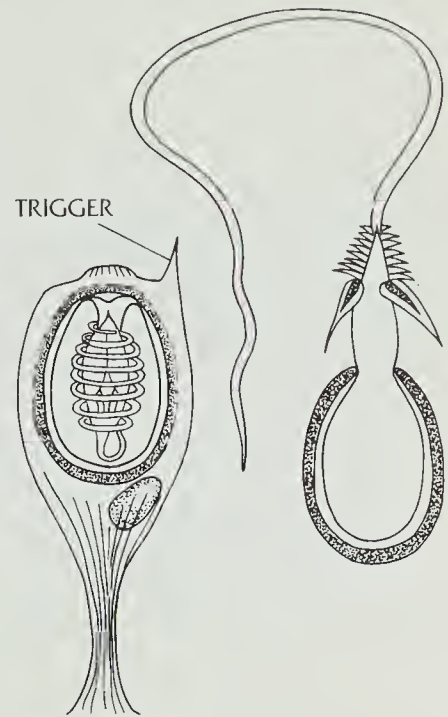


FIGURE 25-9

The combination of both a chemical and a touch stimulus is normally required to cause the discharge of a nematocyst from a cnidoblast.

MAIN IDEA

Extracellular digestion occurs in the gastrovascular cavity, followed by phagocytosis and intracellular digestion. Nutrient and gas transport is by diffusion.

the mouth. This movement is aided by flagella on certain cells of the gastrodermis, which create a current in the direction of the mouth.

MAIN IDEA

Sensory cells are connected into a nerve net. Impulses are distributed equally, and the stimulus of one cell is passed to all the others.

25–18 Coordination In the coelenterates we see the first beginnings of a nervous system that can coordinate the different tissues of the body. The nervous system in the hydra is typical of all coelenterates. Scattered around the body, with the greatest concentration near the mouth, are **sensory** (sen'sər ē) **cells**. Sensory cells are nerve cells that are capable of receiving information, or stimuli, from the environment. From the sensory cells, nerve fibers connect with other sensory cells, forming what is called a **nerve** (nèrv) **net**. If one sensory cell is stimulated, the nerve impulse travels throughout the entire nerve net. Unlike more advanced nervous systems, there are no specific routings for any of the impulses. They travel equally throughout the nerve net. Also unlike more advanced nervous systems, there are no concentrations of nerve cells that interpret or process sensory impulses. In other words, coelenterates have nothing that resembles the brain of more complex animals.

MAIN IDEA

Hydras reproduce asexually by budding or regeneration. Cross-fertilization usually occurs in sexual reproduction. The encapsulated egg can delay its development if conditions are unfavorable.

25–19 Reproduction Hydras and most other coelenterates reproduce both by asexual and sexual methods. When water conditions are favorable, the hydra reproduces asexually by budding. In this process small hydras begin growing out the sides of an adult hydra. Eventually the buds break off and become separate individuals.

When water conditions are unfavorable—for example, when there is increased carbon dioxide in the water—hydras may reproduce sexually. The process begins with the development of structures called the testis and the ovary. The **testis** (tes'tis) produces sperm cells, which are male gametes that are released and swim around in the water with their flagella. The ovary produces an egg cell, which remains attached to the ovary until it is fertilized by a sperm. Normally one hydra produces a testis and another produces an ovary. Occasionally one animal produces both. Such an animal is said to be a **hermaphrodite** (hèr maf'rə dīt).

SCIENCE BACKGROUND

The gastrovascular cavity in the parent hydra and its buds are continuous until just before the buds break off.

The origin of the term *hermaphrodite* is Hermaphroditos, who was the mythical son of the Greek god Hermes, the god of commerce, invention, cunning, and theft, and of Aphrodite, the Greek goddess of love and beauty. Hermaphroditos, the myth held, became united into one body with a nymph, a female spirit.

After fertilization the egg cell begins to divide, and soon the cell mass is surrounded by a tough capsule. Then the capsule, with the partly developed hydra inside, is shed into the water, where it settles. Development may continue and a new hydra will emerge from the capsule in a week or so. However, if conditions are unfavorable, such as in the autumn, development slows down or stops. The cap-

sule enables the partly developed hydra to survive until conditions are more suitable, at which time development continues.

The hydra also has great powers of regeneration. In fact, it was named after Hydra, the nine-headed monster serpent in Greek mythology that grew two new heads for every one that was cut off. If a hydra is sliced into several pieces, each new piece may grow and develop into a new animal.

25–20 Jellyfish There are thousands of medusa-form coelenterates that are called jellyfish (class Scyphozoa). They are much like an upside-down hydra with a very thick mesoglea. The thick mesoglea serves two functions. It makes it easy for jellyfish to float in water. Second, it gives jellyfish structural rigidity, which protects their body from destruction in a rough ocean.

Jellyfish are among the most numerous of coelenterates. Nematocysts in the tentacles are used to paralyze prey.



MAIN IDEA

Jellyfish are medusas with thick mesoglea that makes them buoyant and rigid. The Portuguese man-of-war is a colonial coelenterate having one specialized medusa that acts as a float.

SCIENCE TERMS

mesoglea
cnidoblasts
nematocyst
polyp
medusa
epidermis
gastrodermis
basal disc
gastrovascular cavity
digestive enzymes
extracellular digestion
intracellular digestion
sensory cells
nerve net
testis
hermaphrodite
reefs

Some jellyfish are small, clear, and almost invisible in the upper layers of the ocean. The largest jellyfish is an orange and blue monster, with some specimens being up to 4 m in diameter and having tentacles 30 m long. Large jellyfish are dangerous to humans, who can become paralyzed from the poison in the nematocysts.

Often confused with the jellyfish is a colonial coelenterate called the Portuguese man-of-war. This colonial coelenterate is made up of both polyps and medusas. The colony has one medusa specialized into a large gas-filled float that somewhat resembles the body of a jellyfish. The float is pushed along by the wind, and the colony can be a hazard to swimmers along ocean beaches because of the large dose of poison that can be injected by the colony's many tentacles.

The Portuguese man-of-war is actually a colonial coelenterate. A fish can be seen trapped in the tentacles of the specimen at right.

SCIENCE BACKGROUND

The largest jellyfish belong to the genus *Cyanea*.

Jellyfish swim by contractions of their body, which somewhat resemble the opening and closing of an umbrella.

Jellyfish have few predators, but an exception is the giant sunfish *Mola mola*, specimens of which weigh up to 1 400 kg. They would have to eat many jellyfish for nourishment because the jellyfish body is about 95 percent water.

The Portuguese man-of-war and a close relative called sailor-by-the-wind sometimes cover the water for long distances. After they wash up on beaches, they are still dangerous because the nematocysts can be discharged by handling the tentacles.





Sea anemones are polyp-form coelenterates with numerous tentacles. Most sea anemones are stationary and must attract and capture passing prey.

SCIENCE BACKGROUND

Some hermit crabs place a small anemone on their shell to protect and camouflage them. When they outgrow their shell and get a new one, they pull off the anemone and place it on the new shell. Other crabs carry an anemone in their pincers and hold it out like a weapon if they are threatened.

Small clown fish live amid the tentacles of the anemone and either are immune to the nematocyst poison or are never attacked. They drive other fish to the anemone and may feed on the scraps that are released.

25-21 Sea anemones The sea anemones are polyp-form coelenterates that look like flowers growing on the bottom of oceans and seas (class Anthozoa). Some are brightly colored by algae that grow in their cells. Anemones are most abundant in shallow seas, but some have been found as deep as 10 500 m.

The sea anemones have many more tentacles than hydras. Also their gastrovascular cavity is divided into six separate chambers by walls, or partitions. This greatly increases the amount of gastrodermis that is available to carry out the function of digestion.

25-22 Corals Some of the most important coelenterates are certain polyp-form corals called stony corals. Stony corals produce a calcium carbonate, or limestone, cup that they withdraw into for protection. Most of the stony corals are colonial and grow very close together. Over a period of years, as individuals live and die they build up large bodies of limestone called **reefs** (rēfs). Many corals are brightly colored by algae growing in their cells.

MAIN IDEA

Sea anemones are polyps. Many are brightly colored. Their gastrovascular cavity is divided into chambers, thus increasing the amount of gastrodermis available to digest food.

MAIN IDEA

Corals produce a protective cup that accumulates to form coral reefs. Reefs are important as barriers and hazards to shipping. Reefs provide many habitats for marine life.

ANSWERS TO CHECK YOUR FACTS

1. They have radial symmetry, an interior body cavity with a single opening, a body made up of two layers of cells, and cnidoblasts.
2. The cnidoblast contains a nematocyst, which is a capsule with a coiled thread that can be shot out to entangle or poison prey. Most are located in the tentacles.
3. In fresh water, usually attached to plants or debris. Polyp.
4. The polyp form has the mouth and tentacles facing upward; the medusa has them facing downward.
5. To protect the organism and to create movement. The gastrodermis lines the gastrovascular cavity and protects it. It also creates movement and functions in digestion.



Corals are coelenterates that build up a calcium carbonate shell in which they live. The tentacles protrude from pores in the shell.

ANSWERS TO REVIEW QUESTIONS

1. They lack a cell wall of cellulose; they reach a stage of adulthood; they have the ability of locomotion; they must eat other organisms for food.
2. An animal with bilateral symmetry can be halved by only one central plane; an animal with radial symmetry can be equally divided by any central plane.
3. Sponges have no tissues. Coelenterates have muscle fibers and a primitive network of nervous tissue.
4. Gases are diffused from the water to cells that are in contact with the water, and then from cell to cell to areas not in

Corals can only grow in warm water that is at least 22°C. Therefore coral reefs are found developing in shallow tropical and subtropical waters. The reefs have many important effects on other forms of life. In reef cavities, tunnels, and caves there is a variety of habitats for many different animals. Reefs also form barriers and hazards for boats and ships that must navigate through them.

CHECK YOUR FACTS

1. Name four characteristics of the coelenterate body structure that are unlike those of most other animals.
2. Describe how a cnidoblast functions. Where are they located?
3. Where are hydras found? What body form do they exhibit?
4. Describe the difference in appearance between the two body forms of coelenterates.
5. What is the function of the epidermis? The gastrodermis?

SUMMARY

Zoology is the science that deals with the study of animals. So far, roughly 1 100 000 types of animals have been identified by zoologists. Animals are characterized by their ability of locomotion, their lack of a cell wall, their inability to make their own food, and a stage of development called adulthood. Kingdom Animalia contains 27 phyla, 9 of which contain 99 percent of all animals. The members of phylum Porifera are called sponges. They have no tissues or organs. About 10 000 species belong to phylum Coelenterata.

REVIEW QUESTIONS

1. What are four characteristics of animals that are not found in other organisms?
2. Distinguish between the two types of symmetry.
3. Compare the tissues of coelenterates and sponges.
4. Describe and compare the process of gas exchange in sponges and coelenterates.
5. How is digestion in coelenterates different from that in sponges?
6. List some methods of locomotion used by coelenterates.
7. What methods of reproduction do sponges share with the coelenterates?
8. Describe the three layers of the sponge.
9. What are the three layers of the coelenterate body? How does each layer function?
10. What are the two body forms of coelenterates? Name an example of each type.

ANALYSIS AND APPLICATION

1. Describe the body symmetry of an earthworm, a squirrel, and an elephant. Do trees and other plants have a type of symmetry?
2. Which of the following are correct statements about the human body? Correct each one that is false.
 - a. The fingers are more proximal to the shoulder than the elbow.
 - b. The kneecap is more distal from the hip than the thigh.
 - c. The arms are lateral appendages.
 - d. When lying on your "stomach," your back is a ventral region and your "stomach" is a dorsal region.
 - e. When lying on your "stomach," your head is posterior from your neck.
3. Digestion occurs inside your small intestine. Would this be extracellular or intracellular digestion?

contact with water. Wastes are given off in a similar manner. There is little difference in the processes.

5. Extracellular digestion occurs in the gastrovascular cavity of coelenterates. No similar process is found in sponges.

6. They can creep along a surface, somersault, pull themselves along like a measuring worm, and be borne by wind or ocean currents.

7. Both can reproduce by budding and regeneration.

8. The outer layer is made up of flattened cells that line the exterior of the sponge. The middle layer is gelatinlike and contains wandering amoebocytes. The inner layer lines the pores, canals, and other cavities.

9. The epidermis, which protects the animal and functions in movement; the mesoglea, a noncellular layer that provides rigidity and flotation in some coelenterates; and the gastrodermis, which protects the inner body cavity, functions in digestion, and creates movement

10. Polyp: hydras, corals, sea anemones. Medusa: jellyfish.

ANSWERS TO ANALYSIS AND APPLICATION

1. All three animals have bilateral symmetry. Plants are rarely symmetrical; however, leaves may have bilateral symmetry while many flowers have radial symmetry.
2. **b** and **c** are correct.
 - a. Substitute *distal* for *proximal*.
 - d. Switch *ventral* and *dorsal*.
 - e. Substitute *anterior* for *posterior*.
3. Extracellular digestion.

Investigations 41–42 from *Laboratory Investigations in Biology* can be done with this chapter.

26 Worms



OBJECTIVES

- To understand the basic structural and functional characteristics of flatworms
- To appreciate the roles of flatworms in nature
- To discuss a typical life cycle of a flatworm
- To describe the structure of the nematode body
- To describe the life history and characteristics of such nematodes as *Ascaris*, hookworms, and trichina worms
- To appreciate the structural and functional characteristics of a segmented worm, such as the earthworm
- To understand the basic organ systems of the earthworm

Phylum Platyhelminthes

26-1 Flatworms: general characteristics Any small, flat, or tube-shaped animals that creep or crawl without legs are usually called worms. There are a lot of such animals on the earth—so many that they make up three major phyla of animals. The most primitive of the phyla is the phylum Platyhelminthes, and its members are called flatworms.

All flatworms have bodies with bilateral symmetry. Like the coelenterates, they also have a gastrovascular cavity with one opening. However, unlike the coelenterates, the gastrovascular cavity in flatworms branches throughout the body of the worm.

The flatworms represent two major advances over the coelenterates. First, they have well-developed organs. Organs are structures made up of two or more tissues that work together to perform a specific function.

The second major advance over the coelenterates is the presence of three distinct body layers. These three body layers are a characteristic of all other more complex animals. The body layers appear during the early development of the animal. The outer layer, called the **ectoderm** (ek'tə dêrm), develops into an outer layer of cells that covers the body. In many flatworms this outer layer is an epidermis with cilia and many glands. The inner layer, the **endoderm** (en'dō dêrm), results in the layer of cells lining the gastrovascular cavity. This inner layer is called the gastrodermis. The third body layer, the **mesoderm** (mes'ə dêrm), is between the ectoderm and endoderm. It

MAIN IDEA

Flatworms have bilateral symmetry and a branching gastrovascular cavity. They have organs and three distinct body layers. Two groups are parasites, while one group is free-living.

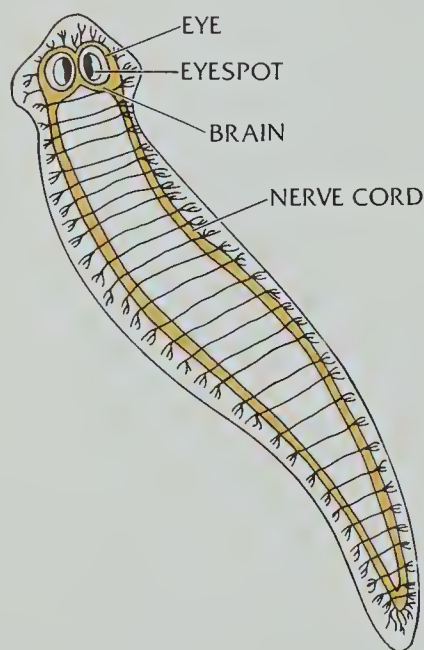
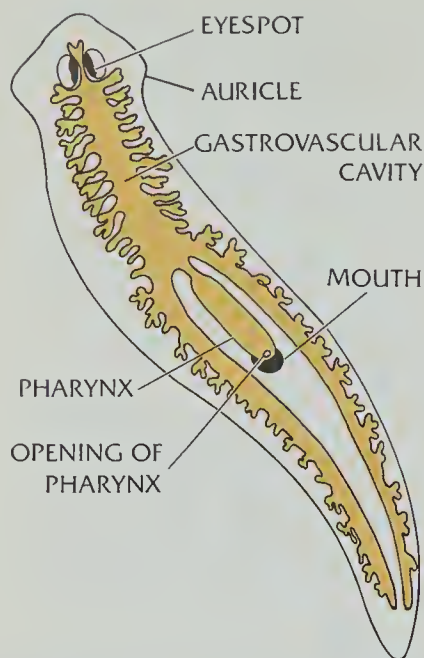


FIGURE 26-1

The internal structure of *Planaria*, including the digestive system and the nervous system, is illustrated in the figure above.

SCIENCE BACKGROUND

A piece of submerged liver anchored in a stream with planarians will usually be covered with them in a few hours.

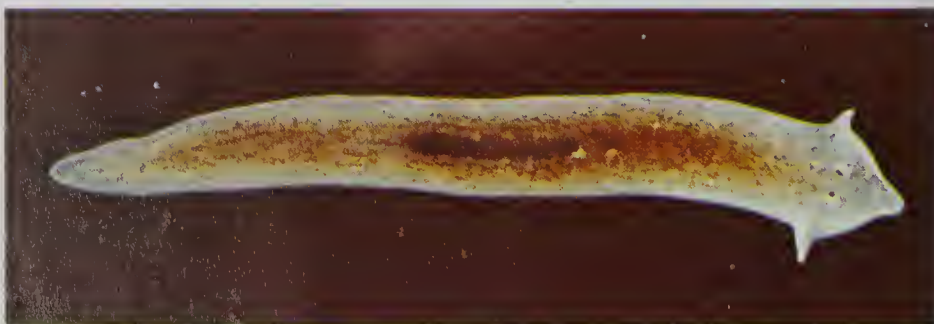
develops into a variety of organs that make up the largest part of the flatworm's body. The muscles and reproductive organs develop from the mesoderm.

The flatworms are classified into three groups or classes. Two groups are **parasites** (par'ə sīts). Parasites live on or in another animal, called a **host**, and obtain part of or all their nourishment from the host. The other group of flatworms is mostly **free-living**. Such animals live an independent life and do not live on or in other animals.

26-2 A free-living flatworm: Planaria If you look closely at a submerged stone in an unpolluted, spring-fed stream, you are likely to see flatworms called *Planaria*. *Planaria* belong to the group of free-living flatworms (class Turbellaria). They are small—about 10 to 12 mm long—and they may be gray or black or almost colorless. By looking closer with magnification, one can observe a head with earlike structures and what appears to be a pair of crossed eyes. The earlike structures are called **auricles** (ôr'ə kəlz). The auricles contain **chemoreceptors** (kem ō ri sep'tərs) that detect or “taste” chemicals in the water. They also sense physical contacts and perhaps the strength of water currents. The structures that look like crossed eyes are called **eyespot**s. The eyespots are **photoreceptors** (fō tō ri sep'tərs), which are light-sensitive organs. They are primitive organs that can only detect light. They cannot focus light rays and see images as we can. Planarians are most active at night. They use their eyespots to detect and avoid light.

Planarians move by a gliding motion. This motion is made possible by two kinds of structures on their ventral surface. In the ventral epidermis there are mucous glands that secrete a layer of mucus under the worm. The ventral epidermis also contains cilia that wave back and forth in the bed of mucus, causing the animal to glide forward.

Planarians are free-living flatworms. Flatworms are the first group of animals to have three distinct body layers.



26-3 Feeding and digestion Planarians feed on either alive or dead small animals. They catch live animals by trapping them with their mucus and by wrapping their body around them. They feed by extending their mouth, which is at the end of a muscular tube in the mid-ventral region. The muscular tube is called the **pharynx** (fär'ingks). By the strong sucking action of the pharynx, the animal is torn into pieces and swallowed.

Inside the gastrovascular cavity some extracellular digestion takes place, from enzymes that are secreted by the gastrodermis. However, much of the food is engulfed by phagocytosis and digested inside the cell.

The gastrovascular cavity branches and rebranches. Therefore it is relatively easy for nutrients from digestion to diffuse to all cells in the body. Undigestible material is released into the gastrovascular cavity from the gastrodermis. Occasionally the planarian will suck water into the gastrovascular cavity, then blow it vigorously through the mouth. This is probably the way undigestible material is flushed out of the gastrovascular cavity.

26-4 Gas exchange and excretion Gas exchange occurs by diffusion between the body cells and the water or air. **Excretion** (ek skrē'shen), which is the general process of eliminating wastes, also occurs from a network of tubules that runs the length of the body and empties through tiny pores. Some wastes eliminated by the excretory system are **nitrogenous** (nī troj'ə nəs) wastes that result from the breakdown of proteins and other nitrogen compounds. More important, the excretory system functions to eliminate excess water that builds up inside the planarian's body.

26-5 The nervous system Planarians have a nervous system with a feature shared by other animals of bilateral symmetry. Planarians have the majority of their nerve tissue concentrated at the anterior end of their body. This is where it is needed as the animal moves forward, searching for food.

In the head of the planarian there are two clusters of nerve cell bodies called **cerebral ganglia** (ser'ə brəl gang'glē ə) (sing. *ganglion*). The branches from the nerve cell bodies extend out to the eyes, auricles, and other parts of the body. The two cerebral ganglia function together as a primitive type of brain. Sensory information is received and interpreted by the cerebral ganglia. Then information is sent out to other parts of the body that need to respond. For example, if a light is shone on a planarian, sensory

MAIN IDEA

Planaria suck in food with their pharynx. Most digestion is intracellular. Wastes are removed from the gastrovascular cavity by sucking in water and then blowing through the mouth.

SCIENCE BACKGROUND

The mucus secreted by planarians is probably distasteful or poisonous to other animals, and it may serve to protect them from predators.

MAIN IDEA

Gas exchange is by diffusion. Excretion also involves a network of tubules that empty through pores. Nitrogenous wastes and excess water are excreted.

MAIN IDEA

Two cerebral ganglia function as a primitive brain. *Planaria* have a limited ability to learn.

nerves in the photoreceptors will carry that information to the cerebral ganglia. That information is interpreted and sent to the muscles, which react. The animal moves away from the light.

Planarians are the favorite experimental animals for zoologists who study how animals learn. Various experiments have shown that planarians are capable of learning simple types of behavior.

MAIN IDEA

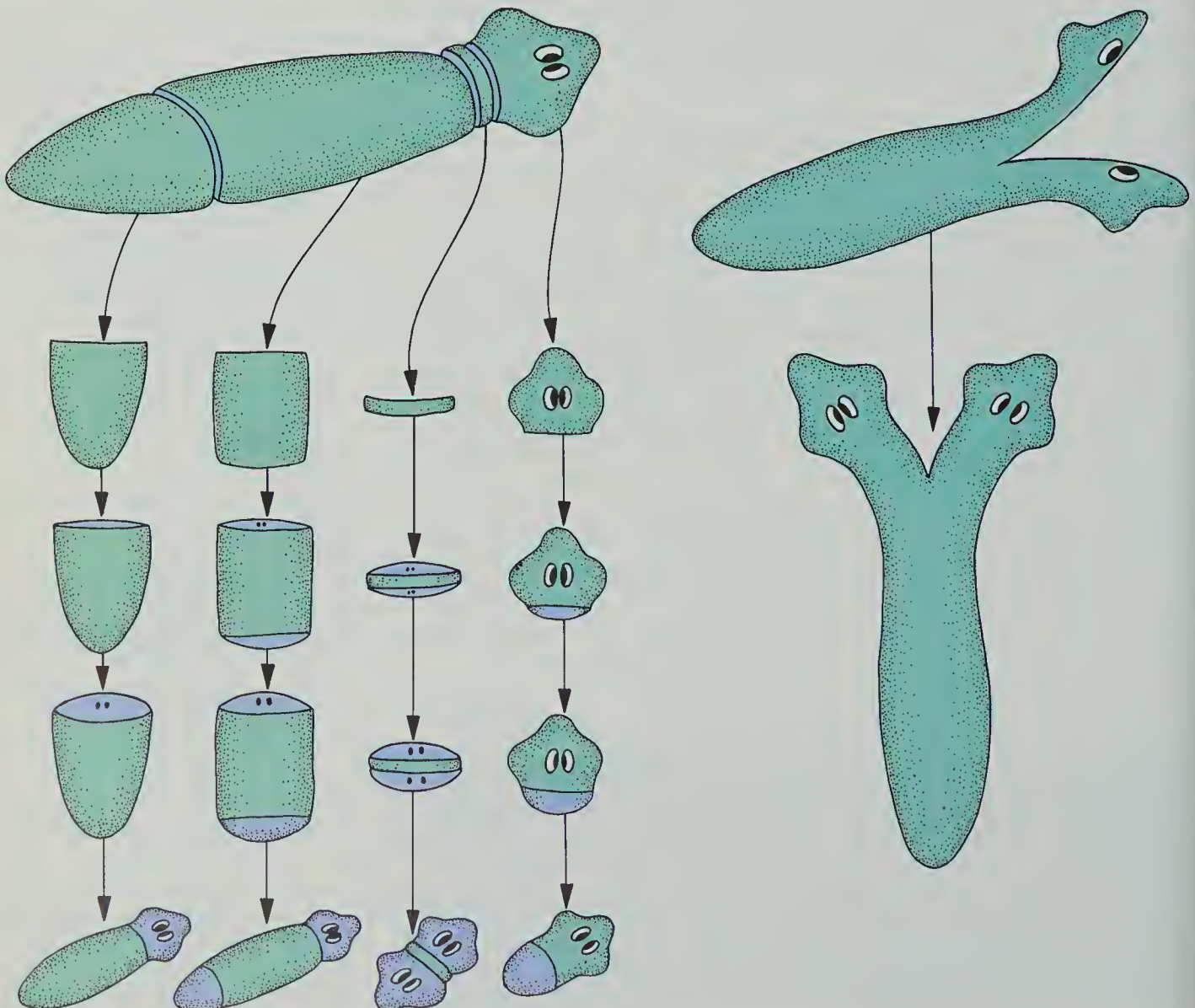
Planaria reproduce sexually and asexually. Most are hermaphrodites. They have great powers of regeneration.

FIGURE 26-2

Planarians have remarkable powers of regeneration. The regenerative process resulting from various cuts of a planarian is shown below.

26-6 Reproduction

Planarians reproduce both asexually and sexually. During asexual reproduction their body constricts, or grows narrower, at the midregion. Then, like a tug-of-war, the head and tail regions pull apart and later grow whatever is missing. The tail region grows a new head, and the head region grows a new tail.



Most planarians are **hermaphroditic**, with sex organs that produce both sperm and eggs. At certain times two planarians will come together and exchange sperm between their bodies. This results in cross-fertilization, when the sperm from one planarian fertilizes the eggs of another. After fertilization the eggs are released in a capsule, which is cemented to the underside of rocks or plants. Development continues and small planarians eventually hatch from the capsule.

Planarians also have great powers of regeneration, and for this reason they are often selected to demonstrate this ability in laboratories. Slice a planarian into several pieces and each piece can grow into a complete individual. A favorite but difficult experiment is to take a very thin slice out of the middle of a planarian. Occasionally, for reasons that are not completely known, that thin slice of planarian will grow a head from each of the cut surfaces.

26-7 A troublesome group: flukes The second group of flatworms includes the parasitic worms called flukes (class Trematoda). The hosts of flukes include a large number of different vertebrate animals—animals with backbones, such as fish, birds, and mammals. Humans can be the unwilling hosts for several different flukes that cause disease.

Parasites are classified into two groups, depending upon whether they live on the inside or outside of their host. **Ectoparasites** (ek tō par'ə sīts) live on the outside of their host. **Endoparasites** (endō par'ə sīts) live inside their host. Ectoparasites and many endoparasites are equipped with hooks and suckers that help them to cling to their host.

Most flukes are endoparasites and require two or more hosts to complete their life cycle. When there are multiple hosts, the one where the parasite lives as a sexually mature adult is called the **definitive** (di fin'ə tiv) **host**. Any other host needed to complete the life cycle is an **intermediate** (in tər mē'dē it) **host**.

26-8 The Chinese liver fluke An example of a fluke that causes human suffering is the Chinese liver fluke. Humans are the definitive host for this fluke. It lives in the liver and feeds on bile, which is a fluid that helps digest fats. The presence of the flukes hinders liver function and in extreme cases can cause death.

The life cycle of the Chinese liver fluke also includes two intermediate hosts. The sexually mature adult releases as many as a thousand eggs a day. These eggs pass out of the

SCIENCE TERMS

ectoderm
endoderm
mesoderm
parasites
host
free-living
auricles
chemoreceptors
eyespots
photoreceptors
pharynx
excretion
nitrogenous
cerebral ganglia
ectoparasites
endoparasites
definitive host
intermediate host
intestine
feces
proglottids

MAIN IDEA

Most flukes are endoparasites and require multiple hosts to complete their life cycle.

MAIN IDEA

The Chinese liver fluke must live in a certain species of snail, then in a certain fish, and then in humans.

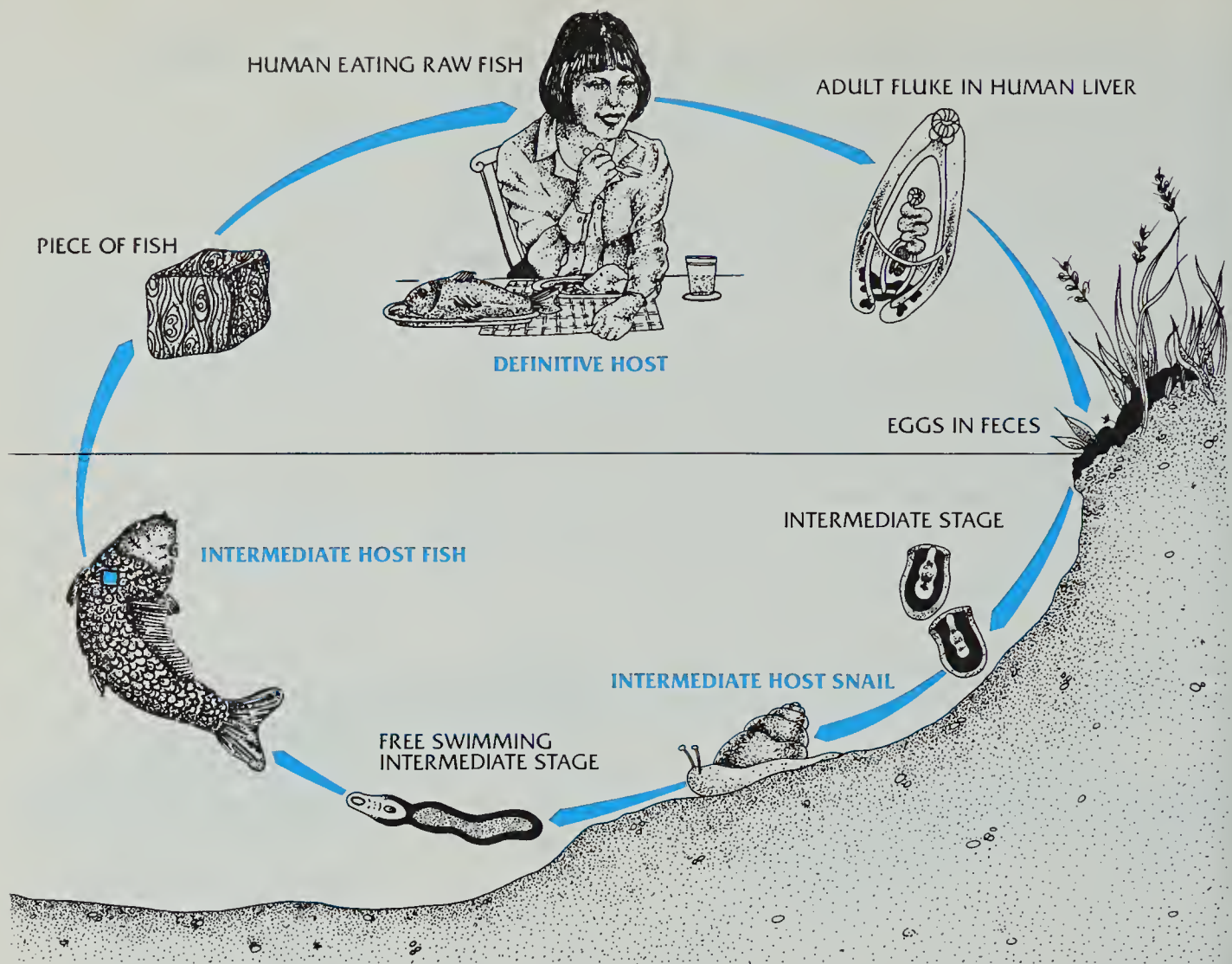


FIGURE 26-3

The Chinese liver fluke requires a particular species of freshwater snail and a particular species of fish as intermediate hosts.

SCIENCE BACKGROUND

The liver fluke lives in the bile ducts. The longevity of liver flukes has only been determined from indirect data. For example, they were found in a Chinese person 25 years after the person left China.

Other troublesome flukes for humans are lung flukes and blood flukes. The latter have an intermediate stage that bores through the skin of people who wade in infected water.

host's body in the **feces** (fē'sēz), which are the semisolid wastes from the large **intestine** (in tes'tən). The egg contains an immature stage of the fluke that is capable of swimming but cannot survive unless it is eaten by a certain species of freshwater snail. The snail is one of the intermediate hosts.

Inside the body of the snail the fluke passes through more stages of development. It reproduces asexually, producing many more individuals. Then, a more advanced stage bores through the snail tissues and out into the water. Once it reaches the water it has a maximum of 48 h to find just the right species of fish and bore into its body. If this occurs, the fish then becomes the second intermediate host. This stage of the fluke lives in the muscles of the fish.

Humans become infected by eating raw or poorly cooked fish. That practice is normal in such countries as Japan, Korea, and China, where the parasite is most common. Also, for centuries people in those countries have

used human feces to fertilize their rice paddies. If it were not for this practice, the flukes could never infect the freshwater snails, and the life cycle could not be completed.

26-9 Tapeworms The third group of flatworms includes worm parasites called tapeworms (class Cestoda). A tapeworm is one of the most highly specialized parasites. It has no mouth or gastrovascular cavity and it does not need either one. The host does the eating and the digestion. The worm lies in the intestine of the host and absorbs nutrients directly into its body by diffusion.

26-10 The beef tapeworm One tapeworm for which the human is the definitive host is the beef tapeworm. Like all tapeworms the beef tapeworm has three regions in its body. The head is barely large enough to be seen with the naked eye and is equipped with suckers. The suckers attach the head to the wall of the intestine, and it is very difficult to break the head loose. Behind the head is a short, slender neck.

The main body of the tapeworm, which may be 4 to 9 m long, consists of a series of segments called **proglottids** (prō glot'idz). The proglottids bud from the neck region and grow larger as they get older and farther away from the neck.

Each tapeworm proglottid is basically a reproductive system designed to produce fertilized eggs. Near the end of the worm, so-called ripe proglottids, full of fertilized eggs, are constantly breaking off and passing out in the feces of the host. Over a year's time it is estimated that one beef tapeworm will release 124 000 eggs. Over the probable 20-year life of such a tapeworm, a total of 594 million eggs would be released. This kind of tapeworm is a highly efficient reproductive machine.

The second phase of the beef tapeworm's life cycle occurs if a cow becomes infected. This can occur if feces

MAIN IDEA

Tapeworms have no systems for eating or digesting. They are totally adapted for life in the host's intestine.

MAIN IDEA

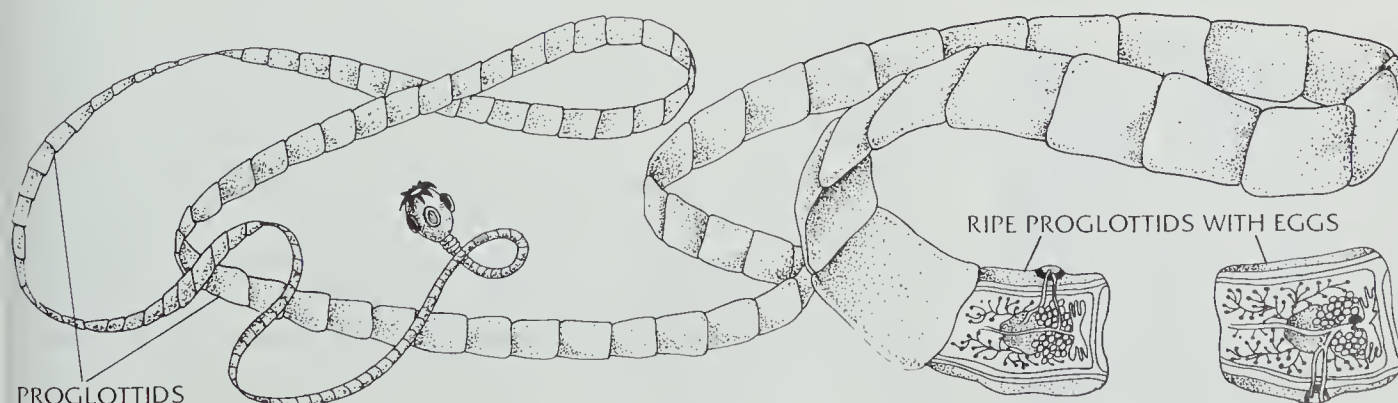
Proglottids of the beef tapeworm are specialized reproductive structures. Humans are infected by eating poorly cooked infected beef. The problem is diminishing because of sanitation improvements.

SCIENCE BACKGROUND

Another less common human tapeworm is the pork tapeworm. Its head has both hooks and suckers. The life cycle and method of infection is about the same as that of the beef tapeworm.

FIGURE 26-4

Ripe proglottids near the end of the tapeworm contain fertilized eggs. These break off and pass out in the feces of the host.



ANSWERS TO CHECK YOUR FACTS

1. Phylum Platyhelminthes.
2. They have well-developed organs and three distinct body layers.
3. The main difference is that the flatworm gastrovascular cavity branches throughout the body of the worm.
4. The ectoderm—the outer layer that covers the animal's body; the endoderm—the innermost layer that lines the gastrovascular cavity; and the mesoderm—the layer that lies between the other two and forms the organs and most of the body mass.
5. The auricles, which detect chemicals and physical contact; and the eyespots, which are photoreceptors.

MAIN IDEA

Nematodes are extremely abundant. Most are free-living.

from an infected person pollute the vegetation eaten by the cow. If the cow eats the eggs, they will hatch in its intestine, and an intermediate state of the worm will bore into the muscles. Later, if the infected animal is slaughtered and the meat is poorly cooked, another human can become infected. Then the life cycle would be completed.

Beef tapeworms are becoming more and more uncommon for two reasons. Modern sanitary conditions make it unlikely that tapeworm-infected human feces will pollute cattle vegetation. Government meat inspectors must approve most meat consumed by the public. These inspectors are trained to identify worm infections in the muscles of slaughtered animals.

Medical treatment for tapeworms is difficult. Medicines usually cause contractions of the intestine and large pieces of the worm may be broken off. However, unless the head also comes loose, it will remain to produce more and more proglottids.

CHECK YOUR FACTS

1. To which phylum do the flatworms belong?
2. What two major advances do the flatworms have over the coelenterates?
3. Compare the gastrovascular cavities of coelenterates and flatworms.
4. Name and describe the three body layers that appear in flatworms and in complex animals.
5. Name two structures that are visible on the head of planarians. What is the function of each?

Phylum Nematoda

26–11 The nematodes The members of the phylum Nematoda are called roundworms or **nematodes** (nem'ə todz). These are small, tube-shaped worms less than 1 cm in length. Some are as long as 1 m.

Nematodes are extremely abundant on the earth. Zoologists have identified about 12 000 species, but it is estimated that there may be almost 500 000 species not yet identified!

Most nematodes are free-living and feed on dead and decaying plant and animal matter. Millions of them can be found in a handful of fertile soil. Ninety thousand were counted in one rotten apple. Nematodes have a valuable role in the recycling of nutrients from generation to generation.

SCIENCE BACKGROUND

Technically the anus of some nematodes is really a cloaca because it is also a reproductive vent.

The pseudocoel is lined with tissue of mesodermal origin on the body-wall side, but is lined with endoderm next to the digestive tube. The term *coelom* is of the same origin as *coelenterate*—both terms refer to “body cavity.”



Most nematodes, or roundworms, are free-living. They live in the soil where they help decompose dead plant and animal matter.

Some nematodes are parasites, and almost every multicellular plant and animal can serve as a host for at least one species. Humans alone can be the host for up to 50 different species of parasitic nematodes.

A nematode expert has given us an example that will help us picture their abundance. Suppose all living things on the earth but nematodes were to disappear. The expert says that by identifying the nematodes, we would still be able to tell where most plants and animals had been and probably what kind some were.

26-12 General body structure The nematodes represent two major advances over the flatworms. They have a full digestive tube that is open at both ends. At the anterior end the mouth takes in the food. Near the posterior end waste materials leave the digestive tube by an opening called the **anus** (ā'nəs).

The second advance is a type of body structure called a **tube-within-a-tube structure**. The tube-within-a-tube structure is found in all other more complex animals. One of the tubes, the inside tube, is the digestive system. It

FIGURE 26-5

The tube-within-a-tube body plan is found in nematodes and in all more advanced animal groups.



MAIN IDEA

Ascaris has an outer cuticle and moves by whiplike motions. It is a parasite that lives in the intestine of mammals. It reproduces sexually and must develop in the lungs before migrating to the intestine.



Two specimens of *Ascaris*, a parasitic nematode sometimes found in the intestine of humans, are shown in the photograph above.

runs the length of the body, from the mouth to the anus. The outside tube is the body wall. Between the two tubes is a body cavity, which, in all other more advanced animals is called a **coelom** (sē'lōm). In nematodes the body cavity is called a **pseudocoel** (sü'də sēl), or false coelom, because it does not develop solely from the mesoderm.

The pseudocoel and coelom are important advances for animals. There is room for many different organs within such a cavity. The cavity provides space where organs such as lungs, heart, stomach, and intestines have room to expand and contract, and to slide by each other as the animal moves. A further advantage of a body cavity is that it may be filled with fluid and, like an air mattress, serve as a protective cushion.

26-13 *Ascaris*: a parasitic nematode A fairly common human parasite in certain subtropical and tropical parts of the world is the nematode called *Ascaris* (as'kər is). A typical adult is 25 to 30 cm long, is light in color, and is pointed at both ends.

Like all nematodes, *Ascaris* has an outer covering called a **cuticle** (kyü'tə kəl). The cuticle is a noncellular structure like the human fingernail, except that it is softer. It is secreted by the layer of cells in the outer body wall of the worm. The cuticle's function is protection and locomotion.

Nematodes have only one layer of muscles in the body wall for locomotion. They run lengthwise. Therefore the muscles cause the worm to double up by pulling mouth and anus toward each other. This stretches the cuticle, which is elastic, and it acts like a stretched rubber band by causing the worm to snap back into a straight position. These whiplike movements seem violent when small nematodes are first observed through a microscope.

Ascaris lives in the intestines of humans, pigs, horses, and other mammals. It feeds on digested food in the host's intestine. It does this by sucking the food into its digestive tube with its muscular pharynx. Nutrients are absorbed by the cells that line the digestive tube. Then they are passed on by diffusion to the liquid-filled pseudocoel, where they flow to all parts of the body.

Reproduction of *Ascaris* is sexual; however, unlike the flatworms, the sexes are separate. The organs of reproduction are in the pseudocoel of both males and females. At certain times male and female worms come together and an unusual amoeboid type of sperm flows into the female organs. After fertilization, development begins, and a female will release about 200 000 eggs per day, which pass out in the feces. A new infection may result when a human

or other animal eats food contaminated with the eggs. Inside the new host the eggs hatch in the intestine. The young worms bore through the intestine wall into the bloodstream, and then travel to the lungs, where they continue developing. Then they are coughed up, swallowed, and transported back to the intestine, where they become adults.

26-14 Hookworms A more serious human parasite is the hookworm. Although much smaller than *Ascaris*, it causes much more body damage.

Inside the mouth of the hookworm are cutting plates that are used to cut into the wall of the intestine, where they live. Also near the mouth are glands that secrete an **anti-coagulant** (an tī kō ag'yə lənt), a chemical that prevents blood from clotting. Equipped with cutting plates and anti-coagulant, the worm grasps and tears the lining of the intestine. Then it feeds by sucking blood with its muscular pharynx. If the worm moves to another location, the cut area may continue to bleed for some time. A hookworm infection causes considerable blood loss and usually a disease called **anemia** (ə nē'mē ə). Anemia occurs when there are not enough red blood cells to carry oxygen to the body cells. Anemia results in an abnormal tired feeling and other problems.

MAIN IDEA

In humans, hookworms cause blood loss and anemia. Eggs hatch in the soil, and the young must enter through the skin, travel to the lungs, and then to the intestine.

Hookworms, shown below, have cutting plates in their mouths to tear into the intestinal wall. They obtain nourishment by sucking blood.



SCIENCE TERMS

nematodes
anus
coelom
pseudocoel
cuticle
anticoagulant
anemia
cyst
trichinosis

MAIN IDEA

Trichina worms form cysts in the muscles. Severe infections result from eating poorly cooked infected pork.

A coiled trichina worm within a cyst can be seen in the muscle tissue in the photograph below.

The female hookworm may release up to 10 000 eggs per day, which pass out in the feces of the host. But unlike those of *Ascaris*, the eggs hatch outside the host, and young hookworm larvae live in the soil. When bare skin, such as a foot, comes in contact with a hookworm larva, the larva may bore through the skin and get into the bloodstream. If so, it moves to the lungs, then follows the route of *Ascaris*. It is coughed up, swallowed, and transported to the intestine.

Both *Ascaris* and hookworm infections used to be quite common in the southern United States. However, in modern times, with good sanitary facilities and with fewer people going barefoot, there has been a great decrease in both types of infection.

26–15 *Trichina* worms Another nematode parasite is the microscopic trichina worm. It may be found in the muscles of pigs, mice, rats, and humans. Normally humans are infected by eating poorly cooked pork muscle from an infected pig. Once reaching the human intestine, the trichina worms reproduce and thousands of offspring bore through the intestine wall. From there they travel in the bloodstream and eventually settle in certain muscles, where they surround themselves within a tiny capsule.



This capsule, made of a limestone material, is called a **cyst** (sist).

It has been estimated that about 16 percent of North Americans are lightly infected with trichina worms, but the infections cause little or no problems. However, it is possible to eat a large number of the worms in pork and receive a severe infection. A severe infection is called **trichinosis** (trik ə nō'sis) and can cause severe pain and death.

Pigs are usually infected with trichina worms by eating infected rats or mice, or by eating uncooked infected pork in garbage. It is difficult for meat inspectors to detect infected pork because of the microscopic size of the cysts. The only sure way to avoid an infection is to kill any worms that might be in pork by thorough cooking.

CHECK YOUR FACTS

1. What two major advances over the flatworms are found in nematodes?
2. What is a coelom? In which animals is it found?
3. How is a pseudocoel related to a coelom?
4. Why are the coelom and pseudocoel important advances?
5. What is a cuticle? What are its functions?
6. How do humans normally become infected with *Ascaris*? Hookworms? Trinchina worms?

ANSWERS TO CHECK YOUR FACTS

1. They have a full digestive tube and a tube-within-a-tube structure.
2. The body cavity between the digestive tube and the body wall. In all animals higher than nematodes.
3. A pseudocoel, unlike a coelom, does not develop solely from the mesoderm. Otherwise, it is basically the same structure.
4. They allow room for the different organs to expand and slide past each other. These cavities can also be filled with fluid and function as a cushion.
5. A noncellular structure that is secreted from cells in the body wall. It functions in locomotion and protection.
6. (a) By eating food contaminated with *Ascaris* eggs; (b) by contact with the skin; (c) by eating poorly cooked infected pork.

Phylum Annelida

26-16 General characteristics The members of phylum Annelida have their body divided into segments and they are called segmented worms. Outside their body these segments often look like a long series of little rings. The earthworm, which is often called night crawler, fishworm, or angleworm, is the most common segmented worm.

The segmented worms have much more complex bodies than the flatworms and roundworms. One of their main characteristics is a well-developed coelom. The coelom is filled with a liquid that helps support the internal organs. Inside the body each segment of the coelom is divided by **septa** (sep'tə), which are wall-like partitions.

Segmented worms have many of the organs and systems that are found in much more complex animals. That is one reason why students in biology classes often dissect the earthworm. In the earthworm the student can observe simple forms of some of the same systems that are found in their own body.

MAIN IDEA

Segmented worms have a well-developed coelom divided by septa at each segment. They are often studied because they have organs similar to those of higher animals.

SCIENCE BACKGROUND

A common segmented worm in freshwater cultures is *Ailiosoma*. It is microscopic, has bundles of setae, and often has green or red spots.

MAIN IDEA

The prostomium contains sensory receptors. The clitellum functions in reproduction. Setae help in locomotion.

SCIENCE TERMS

septa
prostomium
clitellum
setae
esophagus
crop
gizzard
circulatory system
blood
dorsal blood vessel
hearts
ventral blood vessel
hemoglobin
capillaries
nephridia
ventral nerve cord
segmental ganglia
mechanoreceptor
ovaries
testes

MAIN IDEA

Earthworms eat soil. Soil moves through the pharynx, esophagus, crop, gizzard, and intestine. Digestion is extracellular. Wastes pass out through the anus.

SCIENCE BACKGROUND

Some earthworms in Australia, South America, southern Africa, and Ceylon are up to 3 m long.

26–17 The earthworm: external structure The earthworm (class Oligochaete) is a long tube-shaped worm made up of 110 to 180 segments. At the anterior end is a partial segment that overhangs the mouth, called the **prostomium** (prō stō'mē əm). The prostomium has sensory receptors that collect a variety of information for the animal. In the last segment there is a slit-like opening, the anus, where waste material is released from the digestive tube.

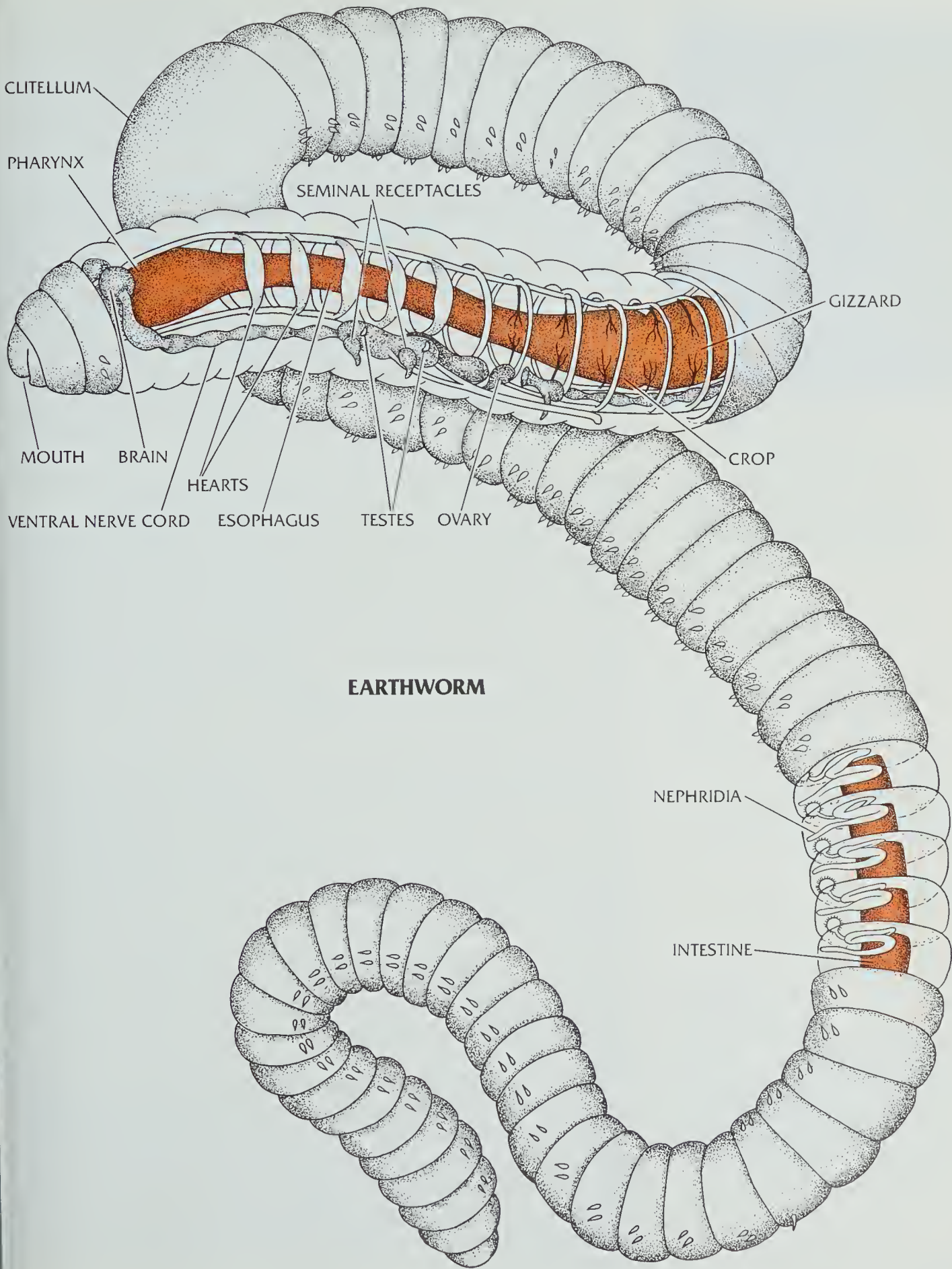
Surrounding the earthworm between segments 32 and 37 is a wide band that is usually light brown in color. This band is the **clitellum** (kli tel'əm), which functions during reproduction.

One of the unique characteristics of the earthworm is the presence of hairlike bristles on its body. These bristles, called **setae** (sē'tə), cannot be seen but can be felt by rubbing the ventral side of the worm. The setae have two functions. They help during locomotion by anchoring the body while internal muscles contract and pull the animal forward. (Try thrusting one of your own legs forward if the other one is not anchored, as when on ice, and you can better appreciate the function of the setae.) Also, when earthworms come aboveground at night, they usually leave their tail region in the hole. The setae anchor the tail and enable the worm to draw back into the hole quickly. (Try pulling an earthworm out of its hole and you can appreciate the strength of its muscles and the anchoring role of its setae.)

26–18 Feeding and digestion Earthworms eat soil. In fact, in ground that is tightly packed, that is how they are able to move through the soil; they eat their way through.

As the soil moves into the mouth it is sent backward by contractions of the muscular pharynx. From there it moves through a slender tube, the **esophagus** (ē sof'ə gəs), and into a thin-walled storage organ, the **crop** (krop). Beyond the crop the thick-walled, muscular **gizzard** grinds the food, helped by sand and other solid minerals in the soil. After the gizzard, the remainder of the digestive tube is an intestine that extends the remaining length of the body.

Digestion in the intestine is extracellular by enzymes secreted from cells that line its wall. The material that is digested includes seeds, eggs from small animals, and a variety of dead and decaying plant and animal matter. Farther back in the intestine, digested nutrients are absorbed by the lining cells, and undigested matter is passed out through the anus.





The earthworm is the most familiar annelid. Earthworms are valuable soil animals, decomposing organic matter and keeping the soil loose enough for oxygen to penetrate.

MAIN IDEA

Gas is exchanged between capillaries in the skin and the air in the soil.

MAIN IDEA

Earthworms have excretory organs called nephridia that are the forerunners of the kidneys.

26–19 Transport The function of transport in the earthworm is mainly carried out by a special **circulatory** (sēr'kyə lə tōr ē) **system**. The circulatory system consists of a red fluid called **blood** and a network of closed tubes, or vessels, through which the blood continually circulates throughout the body.

One of the main vessels in the circulatory system is the **dorsal** (dôr'səl) **blood vessel**. It collects blood from the rear part of the body and pumps it forward by a squeezing action of its muscles. By looking closely at the dorsal side of a living earthworm, this vessel and the red blood inside can be observed.

In the region of the esophagus, five pairs of enlarged vessels called **hearts** branch off the dorsal blood vessel. The hearts also pump blood. They connect with the second major vessel, the **ventral** (ven'trəl) **blood vessel**, which runs underneath the digestive tube. Here some of the blood goes forward to the anterior end of the animal. Most of the blood goes back beneath the digestive tube.

The blood of the earthworm is red because of the pigment **hemoglobin** that is dissolved in it. The hemoglobin combines with oxygen and transports it to cells throughout the body. Vertebrates, such as humans, also have hemoglobin in their blood; however, there is one major difference. The hemoglobin in vertebrate blood is found inside special cells (red blood cells) that flow in the blood, not in the liquid as in the earthworm.

26–20 Gas exchange There is no special system for gas exchange in the earthworm. Gases are exchanged by diffusion directly between the **capillaries** (kap'ə ler ēz) in the skin and the air in the soil. Capillaries are tiny blood vessels with a wall that is only one cell layer thick. The moisture on the skin of the worm aids in the diffusion of the gases.

After a heavy rainfall it is common to see earthworms on the surface of the ground. The rainwater fills the air spaces in the soil, and the earthworms have to come to the surface to obtain oxygen from the air.

26–21 Excretion Some of the nitrogenous wastes pass directly into the fluid of the coelom. Other nitrogenous wastes are carried in the blood. In both cases these wastes end up being eliminated from the body by special excretory organs called **nephridia** (ni frid'ē ə). Nephridia are found in almost all the segments. They are the forerunners of organs called kidneys, which are found in vertebrates.

26-22 Coordination The earthworm has a much more complete nervous system than the flatworms and roundworms. It has a two-lobed brain and one main nerve cord, the **ventral nerve cord**, that runs the length of the body. At each segment there are swellings of nerve tissue, the **segmental** (seg men'təl) **ganglia**, which have branches that extend into each segment.

The earthworm has a number of receptors that pick up different kinds of information. It has photoreceptors that detect light from which the worm reacts negatively. Another type of receptor is called a **mechanoreceptor** (mek ə nō ri sep'tər), which detects vibrations. The mechanoreceptors are forerunners of organs such as the ear, which detects sound vibrations. A third type of receptor is a chemoreceptor that detects the presence of certain chemicals. Chemoreceptors are forerunners of organs that taste and smell.

26-23 Reproduction Earthworms are hermaphroditic and reproduce sexually. The main female organs are the **ovaries**, which produce eggs. The chief male organs are the **testes**, which produce sperm. Self-fertilization does not occur in the earthworm. Instead, at certain times two worms come together and exchange sperm. This results in cross-fertilization.

After the sperm exchange, each worm produces a slime band around its clitellum. Eggs are deposited in the slime band. Then the slime band slides forward and sperm are released upon the eggs. The slime band continues to move forward until it slides off the front of the worm. Then the ends are sealed and the fertilized eggs develop inside the closed capsule.

Earthworms also have limited powers of regeneration. If a worm is cut in two, the front half will often grow another back half. However, the back half may grow only a few segments, but it will develop the organs found in the anterior part of the body.

26-24 The leech Another common segmented worm is the leech (class Hirudinea). It is most often found in stagnant or slow-moving bodies of freshwater. The typical leech has a completely different way of life than the earthworm. Most leeches are free-living for the majority of their lives but are ectoparasites while they are feeding.

Most leeches feed by attaching themselves to a vertebrate animal and sucking its blood. Such leeches, called bloodsuckers, usually have several adaptations that help them with their feeding. Most have two suckers on their body,

MAIN IDEA

Earthworms have a two-lobed brain and a ventral nerve cord with ganglia. They have receptors to detect light, vibrations, and chemicals.

MAIN IDEA

Earthworms are hermaphrodites and reproduce sexually. They also have limited powers of regeneration.

SCIENCE BACKGROUND

Grafting also can be done. In the laboratory very long worms have been produced by grafting worms end-to-end.

MAIN IDEA

Most leeches feed by sucking the blood of vertebrates. They have suckers, sharp jaws, painkillers, and anticoagulants to aid in feeding.

The leech is a parasitic annelid. It lives by attaching to the outside of the body of a vertebrate animal and sucking the blood.

ANSWERS TO CHECK YOUR FACTS

1. Partitions that divide the segments of annelid coeloms. The band between segments 32 and 37 of the earthworm.
2. The prostomium. It contains sensory receptors.
3. Bristles found on the body of the earthworm. They anchor the worm so that it can contract to move forward or to return quickly to its hole.
4. Mouth—esophagus—crop—gizzard—intestine—anus.
5. A pigment that combines with oxygen and transports it to cells. In earthworms it is in the liquid blood; in humans it is contained in red blood cells.

ANSWERS TO REVIEW QUESTIONS

1. *Ascaris* and trichina worm—phylum Nematoda; Leech—phylum Annelida; *Planaria* and Chinese liver fluke—phylum Platyhelminthes. The *Planaria* and Chinese liver fluke are more primitive than the others.
2. The anus and a pseudo-coel—phylum Nematoda; blood, a coelom, and nephridia—phylum Annelida; three distinct body layers and ganglia—phylum Platyhelminthes.
3. The leech is an ectoparasite; the tapeworm is an endoparasite. Both animals have suckers.
4. The Chinese liver fluke must live in a certain species of snail and a certain fish. The beef tapeworm lives in a cow. No.



one surrounding the mouth and another at the posterior end of the body. The suckers help them to remain attached to the host while they are feeding. Another typical adaptation is a set of sharp jaws that enable the leech to cut the skin of the host. Also the mouth may secrete a special chemical that is both an anticoagulant and a pain killer. That way the leech can continue to feed on freely flowing blood without the host animal knowing it is present. A final adaptation is the ability of the bloodsucker to stretch its body to two or three times its normal size as it is feeding. That way, after it falls off the host body, it may not have to find another host and eat again for several months.

Years ago it was normal for every local pharmacy to have a jar of bloodsuckers, called medicinal leeches, for sale. These leeches were bought by people who applied them to their skin to get rid of blood. Excess blood was thought to be the cause of a number of different ailments. The process called blood letting, or the removal of blood, was thought to be beneficial. Leeches were used instead of other techniques because they did the job painlessly.

CHECK YOUR FACTS

1. What are septa? What is the clitellum?
2. What structure is found at the anterior end of the earthworm? What is its function?
3. What are setae and how do they function?
4. Trace the path of food in the earthworm from the mouth to the anus.
5. What is hemoglobin? Where is it found in earthworms? In vertebrates?

SUMMARY

The most primitive of the worms are the flatworms—members of phylum Platyhelminthes. Unlike the more primitive animals, flatworms have three distinct body layers and well-developed organs. Two groups of flatworms, the flukes and the tapeworms, are parasites. The members of the phylum Nematoda, called roundworms or nematodes, are the most abundant of the worms. Advances seen in this phylum include a full digestive tube with both a mouth and an anus, a tube-within-a-tube structure, and a pseudocoel. The segmented worms, or annelids, include the earthworm and the leeches. They represent many advancements over the other worms.

REVIEW QUESTIONS

1. To what phylum do these organisms belong: *Ascaris*, *Planaria*, leech, Chinese liver fluke, trichina worm? Which are the most primitive?
2. In which phylum do we first see the following: a second opening in the digestive tube—the anus; blood; a pseudocoel; a coelom; three distinct body layers; ganglia; nephridia?
3. The leech and the beef tapeworm represent two different groups of parasites. What are these groups? How are these two animals equipped to adhere to their host?
4. List the intermediate hosts of the Chinese liver fluke and the beef tapeworm. Does *Ascaris* have an intermediate host?
5. What part of the body is developed from the mesoderm in higher animals?
6. In what ways is the digestive system of earthworms more advanced than that of planarians?
7. Name five structures that are likely to be found in any one segment of an earthworm. List one function of each.
8. What structures make up the main body of the beef tapeworm? What function do these units serve?
9. Using the earthworm as an example, give two reasons why the coelom is an important advancement.
10. List four adaptations that help leeches survive.

ANALYSIS AND APPLICATION

1. Animals such as the beef tapeworm produce great quantities of eggs. Why, do you think, is this so?
2. Why are earthworms beneficial to many plant populations?

5. The coelom and its contents.

6. It has specialized parts: the esophagus, crop, gizzard, and intestine. It passes wastes through the anus, instead of back out through the mouth. It grinds food and then digests it extracellularly.

7. Septa—divide the coelom into segments; nephridia—eliminate body wastes; setae—anchor the body to allow the worm to move; segmental ganglia—act as junctions in the nervous system; capillaries—carry blood and assist in gas exchange. There would also be part of the dorsal and the ventral blood vessels and part of the ventral nerve cord.

8. Proglottids. They are reproductive units.

9. The cavity provides space where organs such as lungs, stomach, and intestines have room to expand and contract. In addition, the body cavity may be filled with fluid and serve as a protective cushion.

10. They have suckers to adhere to the host, sharp jaws to break the skin of the host, a chemical that acts as an anticoagulant and a painkiller, and they can expand their body to take in more blood and thus feed less often.

ANSWERS TO ANALYSIS AND APPLICATION

1. The chances of a particular egg completing a life cycle are very slim. Therefore, the species, if it is to survive, must produce very large quantities of eggs.
2. They improve the ability of the soil to support plant life by making it more porous. This facilitates root growth and improves water retention.

Investigation 43 from *Laboratory Investigations in Biology* can be done with this chapter.

27

Mollusks and



OBJECTIVES

- To describe the three basic characteristics of a mollusk
- To discuss the basic structural and functional characteristics of gastropods, bivalves, and cephalopods
- To understand that echinoderms are exclusively marine animals, have radial symmetry, and have a unique water-vascular system
- To describe common echinoderms, such as the brittle star, sea urchin, and sea cucumber

Echinoderms

Phylum Mollusca

27-1 General characteristics Phylum Mollusca includes over 100 000 species and is the second largest of all the animal phyla. The members of this phylum are called **mollusks**, or “soft-bodied animals.” They include snails, slugs, clams, oysters, squids, and octopuses. Most of the mollusks live in marine waters, but some live in freshwater and a few live in moist terrestrial areas.

The mollusks include some of the largest and most intelligent of all the invertebrates. The giant squid, which lives deep in the ocean and is seldom seen, may be up to 15 m long. Squids and octopuses have relatively large brains. Captive octopuses have been trained to respond to both reward and punishment.

Mollusks also include some important food animals. Snails are highly regarded as food in many countries. In North America they are found on menus of some restaurants as escargots or abalones. Oysters, clams, and scallops are popular seafoods. Small squids are highly prized in many countries and are often cooked in sauces made from the black ink stored in their body.

One unique characteristic of the mollusks is the presence of a muscular **foot**. Mollusks such as snails and clams use the foot for locomotion. Squids and octopuses have a foot that is modified into arms with suckers, which are used to capture prey.

A second unique characteristic of mollusks is a structure called the **mantle**. The mantle is a fold of tissue on the dorsal surface of the body that covers the internal organs.

MAIN IDEA

Mollusks number over 100 000 species. Some are important food animals. They are characterized by a foot, a mantle, and well-developed respiratory and transport systems.

SCIENCE BACKGROUND

Some zoologists think there are probably more species of nematodes than of mollusks, but the species have not yet been identified and described.

Paleontologists are often by necessity mollusk experts because mollusks make up a large part of the fossil record. Of course, this is because of their shells, which are much more likely to survive than are animals with soft bodies.

In most mollusks the mantle's main function is the production of a limestone shell for the protection of the animal.

A third characteristic of mollusks is their well-developed gas exchange, or respiratory, system. With animals as large as most mollusks, it is not possible for simple diffusion through the skin to supply adequate oxygen. The respiratory systems of mollusks vary depending upon where they live. Aquatic animals have organs called **gills**, which have a large surface area and are full of capillaries. Gases diffuse across a thin membrane that covers the gills and capillaries.

Large animals also need an efficient transport system to make sure all cells obtain food and oxygen. The transport system in mollusks is a very efficient circulatory system, which includes a two- or three-chambered heart.

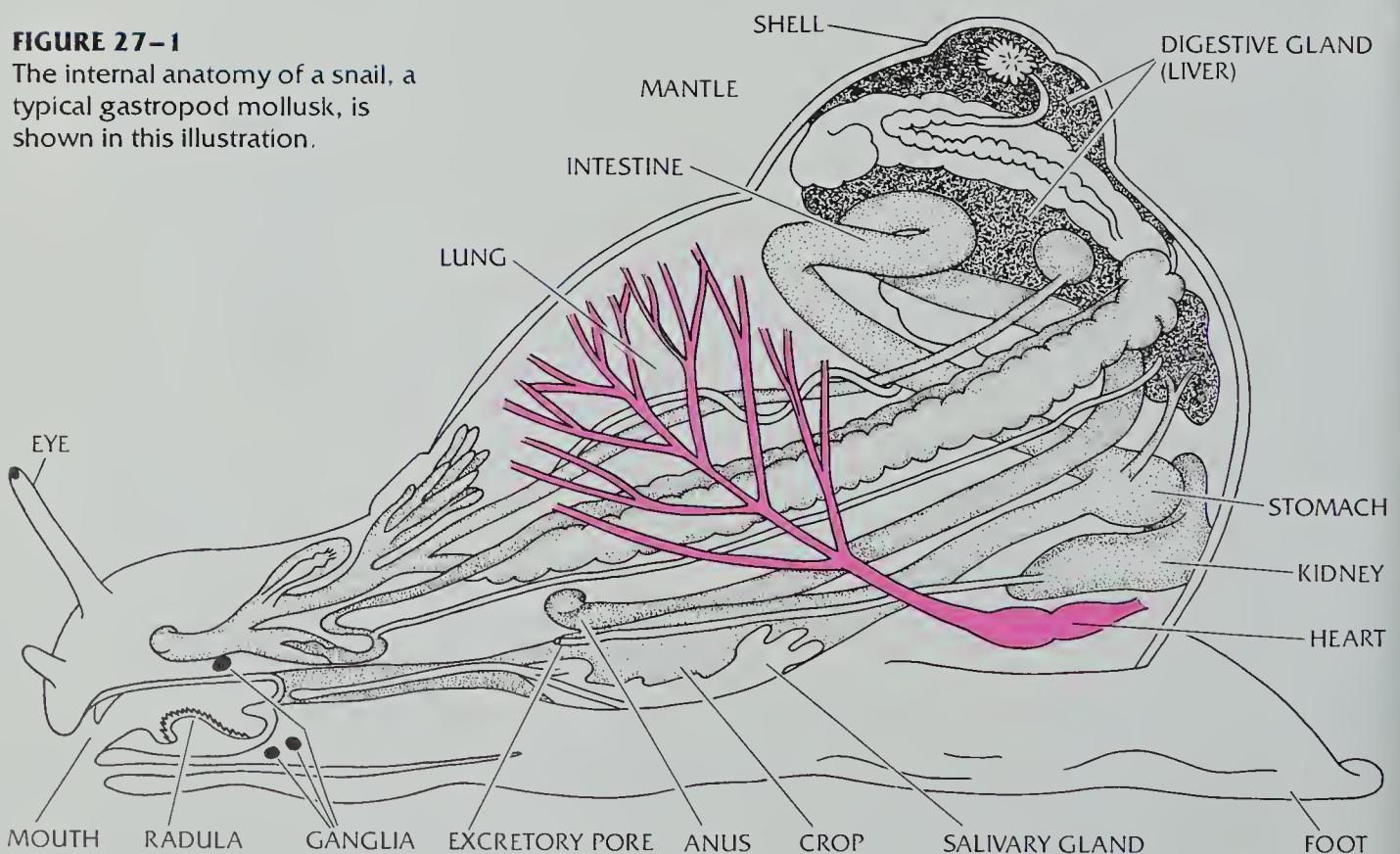
MAIN IDEA

Gastropods include snails and slugs. Snails secrete a shell from their mantle. Their foot functions in locomotion. Most snails use their radula to feed on plant matter.

27-2 The gastropods The members of the largest group of mollusks are called **gastropods** (class Gastropoda). The name means “stomach-footed animal,” a good descriptive name. Snails have a large foot on their ventral side. The foot secretes a bed of slimy mucus, on which the snail glides with the help of cilia on the foot. However, snails are not known for their rapid movement, hence the common expression that a slow person moves at a “snail’s

FIGURE 27-1

The internal anatomy of a snail, a typical gastropod mollusk, is shown in this illustration.





pace.” Actually snails do not need to move rapidly to protect themselves. When danger threatens, the snail withdraws into its curved shell, where it is usually safe from its predators.

Snails have a well-developed head with two pairs of retractable tentacles. On the tips of the posterior pair of tentacles are two eyes. Both pairs of tentacles have mechanoreceptors that are sensitive to touch.

Just behind the mouth, in the floor of the pharynx, is one of the snail’s most unique organs. This organ, called the **radula**, is covered with rows of tiny teeth and can be extended like a tongue. Most snails feed on plants, and the radula is used to scrape plant matter and carry it back into the pharynx.

Snails secrete a variety of different shells from their mantle. Some of the large seashells and conch shells have many interesting shapes and are valuable for decorative purposes. Slugs are close relatives of snails that do not produce shells.

27-3 Snails: internal functions Most internal systems of snails are similar to but more advanced than those in the segmented worms. The digestive tube includes a pharynx and a crop. It also includes a muscular **stomach**, which is both a food-grinding and a digestive organ. Beyond the stomach is a coiled intestine, where digestion continues and nutrients are absorbed.

The snail’s shell serves a protective function, since the snail can withdraw into it if danger threatens. Slugs are close relatives of snails.

SCIENCE BACKGROUND

Most snails are algae grazers or herbivores of some kind. However, there are some carnivorous snails and some that are deadly to humans. Some carnivorous snails have a radula with poison-covered darts that are shot into prey. A cone-shell snail of the Great Barrier Reef off Australia can stab with its radula, and its poison is deadly to humans.

MAIN IDEA

The digestive tube of snails includes a stomach. Gas exchange is through gills or a primitive lung. Snails are hermaphroditic and reproduction involves cross-fertilization.

Gas exchange in most snails occurs in gills. Also many freshwater and terrestrial snails have in the mantle a cavity that functions as a primitive type of **lung**. Such a lung is basically an air space that is surrounded by capillaries, where oxygen and carbon dioxide can be exchanged.

Snails have an efficient circulatory system, with a two-chambered heart as a pump. The nervous system is well developed, with a **cerebral ganglion** near the pharynx. Like earthworms, snails are hermaphroditic and reproduce sexually after a sperm exchange that results in cross-fertilization.

MAIN IDEA

Bivalves are headless filter feeders. Clams use their foot for locomotion. Some bivalves are prized as food. Oysters make pearls by secreting mother-of-pearl in layers over foreign particles.

SCIENCE BACKGROUND

Some bivalves use a combination of shell, foot, and chemical secretions to bore into submerged objects. The shipworm (*Teredo*) bores into submerged piling of wharves and creates costly damage.

The giant clam of the Indo-Pacific coral reefs grows up to 1 m long and weighs up to 200 kg. At least part of its food is furnished by algae that live in amoeboid cells in its blood. The clam opens its shell to provide light for the algae, which are eventually digested.

27-4 The bivalves A second major group of mollusks includes animals called **bivalves** (class Pelecypoda). Common bivalves are clams, oysters, and scallops. They get their name from their unique shell, which is made up of two halves or “valves.” The two valves are hinged and are attached to powerful muscles that can snap them shut when danger threatens.

The bivalves are unlike most of the other mollusks because they lack a head. They are filter-feeders, like the sponge. Inside their body are tubes lined with cilia, which create a steady flow of water through their body. The flowing water brings food, which is filtered out and passed through their digestive system. The moving water flows over gills, where gas exchanges occur.

The scallop, shown below, is an example of a bivalve mollusk. Many bivalves, including scallops, clams, and oysters, are good food sources.





The giant clam of the South Pacific may measure over 1.5 m in diameter and can weigh over 225 kg.

Bivalves such as the clam have an interesting type of locomotion. They extend their large muscular foot beyond their shell and into mud or sand. Next, the tip of the foot is filled with blood and it swells, forming an anchor. Then the muscles in the foot are contracted, pulling the animal forward.

Bivalves such as clams, oysters, and scallops are important sources of food. Certain kinds of oysters, called pearl oysters, are valuable because of the pearls that they grow. The actual pearl results when a foreign object enters the area between the shell and the mantle. The oyster protects itself by secreting layers of material called mother-of-pearl around the foreign object. After several years that multi-layered object becomes the jewel that we know as a pearl. In the early part of this century the Japanese found a way to get pearl oysters to grow pearls. They plant tiny grains of mother-of-pearl in the oysters, then put them in wire cages in selected parts of the ocean where they can later be found. Within a few years many of the oysters will grow what have come to be called cultured pearls.

27-5 The cephalopods The members of the third major group of mollusks are called **cephalopods** (class Cephalopoda), which means “head-footed animals.” The cephalopods have their foot divided into arms with suckers. The squid is a cephalopod with ten arms. The octopus, another cephalopod, has eight arms. As mentioned earlier, some squids are very large. But so are some octopuses, which may reach diameters of 9 m. These are extremely dangerous to divers in some regions of the Pacific.

MAIN IDEA

Cephalopods have their foot divided into arms with suckers. Squids can move by shooting water from their body and are usually luminescent. Squids and octopuses have ink sacs, pigment bodies, and a camera eye.

SCIENCE BACKGROUND

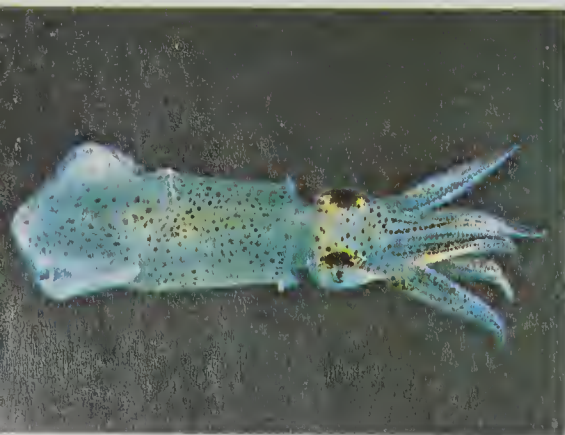
On November 2, 1887, Newfoundland fishermen found washed up on the shore a giant squid that measured 16.8 m in length, with the head and body making up 6.1 m of that length. Sperm whales with tentacle scars on their body and huge tentacles in their stomach have been caught. This has led to speculation that there are tremendous undersea battles between these two giants.

The cuttlefish—a broad, flat cephalopod—is a valuable source of a sepia-colored ink that is used by artists. Also valuable is its “pen,” or internal supporting shell, which is cut up and put in canary cages as cuttlebone, a source of calcium.

SCIENCE TERMS

foot
mantle
gills
radula
stomach
lung
camera eye

The giant squid, a relative of the small squid shown here, is the largest invertebrate in the world, reaching a weight of over 1800 kg.



While some species of *Octopus* grow quite large, most species are fairly small and not aggressive toward humans.

The cephalopods have several interesting adaptations that enable them to escape predators. The squid has a way of shooting water out of its body that causes a movement like jet propulsion. Both squids and octopuses have ink sacs that can be emptied to produce a black cloud, behind which they can escape from predators. The ink also may paralyze the predator's sense of smell. Also both animals have pigment bodies in their skin that can be enlarged or contracted. This allows them to change color and blend with their surroundings. Ninety percent of the squids are luminescent, that is, they give off light. Zoologists are not sure how this adaptation helps them.

The most remarkable adaptation of the cephalopods is their eye. It is called a **camera eye** because it has a lens that can change its focus. Such a camera eye is not found in any other invertebrate animals. However, it is very similar to the camera eye of vertebrates except for one difference. Our own camera eye can focus because of muscles that change the thickness of the lens. In the cephalopod camera eye the focus is changed by sliding the lens back and forth. This latter method is how an actual camera focuses. Therefore the cephalopod eye is actually more like a camera than is our own eye.

CHECK YOUR FACTS

1. Describe the mantle and state its function.
2. What are gills?
3. How does the foot function in gastropods? In cephalopods?
4. What is a radula?
5. What digestive organ is found in gastropods that is lacking in annelids?
6. How are bivalves unlike other mollusks?
7. Name two ways in which bivalves are of economic value to humans.

Phylum Echinodermata

27-6 General characteristics The members of phylum Echinodermata are called **echinoderms**, which means “spiny-skinned animals.” The spines found in echinoderms are outgrowths from an internal skeleton, which is made up of limestone plates of different sizes. The presence of the internal skeleton is one of the main characteristics of echinoderms.

Another characteristic of echinoderms has to do with where they live—their habitat. All of them live in marine waters. Phylum Echinodermata is the only major animal phylum that does not have even one species living in fresh water or on land.

A third major characteristic of echinoderms is their body symmetry. Adult echinoderms have radial symmetry, often with five arms, or arms in multiples of five. They have no head or a region that could be compared to a head. Larval echinoderms, which are incompletely developed, have bilateral symmetry.

The fourth major characteristic of echinoderms is truly unique within the animal kingdom. This characteristic is their **water-vascular system**, which is a network of water-filled tubes in the coelom of their body. Also unique are the **tube feet**, which are connected to the water-vascular system and are used for locomotion by some echinoderms. Both the water-vascular system and the tube feet will be discussed in more detail.

27-7 The starfish One of the best-known echinoderms is the starfish, which is also called the sea star (class Asteroidea). Starfishes are common in the shallow waters along the seashore. They usually have five arms and range in diameter from 1 cm to 100 cm.

ANSWERS TO CHECK YOUR FACTS

1. The mantle is a fold of tissue on the dorsal surface that covers the internal organs. It secretes the protective limestone shell.
2. Respiratory organs that allow gas exchange between capillaries and water in the environment.
3. In locomotion. In capturing prey.
4. A tooth-covered organ in snails that is extended from the mouth to obtain food.
5. The stomach.
6. They lack a head, they are filter-feeders, and their shells are unique.
7. They are important sources of food and they produce pearls.

MAIN IDEA

Echinoderms are marine animals that have an endoskeleton, radial symmetry, and a unique water-vascular system with tube feet.

SCIENCE BACKGROUND

Because of similarities in their embryonic development, the echinoderms are considered to be close relatives of the chordates. Other evidence includes a similarity between the echinoderm larvae and the prechordate acorn worm. The echinoderms are an ancient group of animals with a fossil record dating back to Cambrian times, about 500 million years ago.

MAIN IDEA

The starfish body consists of the central disk and the arms. The mouth is on the ventral side of the disk.

The starfish has two main body regions: the central region, or **disk**, and the arms. The mouth is on the underside of the disk. Also on the underside of the starfish are deep grooves that extend from the tip of each arm to the mouth.

MAIN IDEA

The water-vascular system forces certain tube feet to become extended. The tube feet are used for locomotion and for obtaining food.

27–8 The water-vascular system Inside the coelom of the starfish is a network of closed tubes, or canals, that make up the water-vascular system. In each arm there is a canal that is connected to two rows of tube feet. To imagine how the system works, think of blowing up an animal balloon with little feet on it. You first blow and inflate the main part of the balloon. Then, with a little more pressure, the little feet pop out. The tube feet operate somewhat the same way. Water is always under some pressure in the canals of the water-vascular system. The pressure is created by the squeezing action of muscles. With increased

The starfish is the most familiar member of the phylum Echinodermata. What type of symmetry does this animal have?



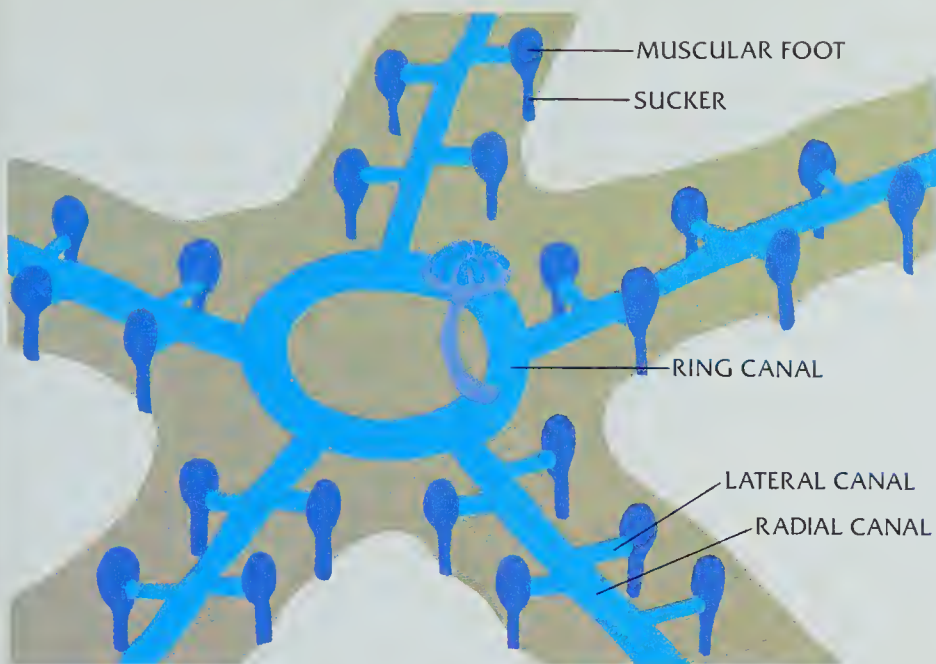


FIGURE 27-2

The water-vascular system of a starfish and its relationship to the tube feet are shown in this diagram.

pressure in one of the arms, the water is forced into the hundreds of tube feet and they expand, or pop out. On the ends of the tube feet there are suckers, which can firmly attach the tube feet to solid objects.

Starfish locomotion is the result of expansion and contraction of the tube feet. When the tube feet are expanded, they reach out and attach to a solid object. Then, when they are contracted, the starfish is pulled forward.

Starfishes also use their tube feet to obtain food. Among their favorite foods are bivalves such as clams and oysters. To obtain this food they crawl upon a clam, for example, and the clam immediately snaps shut its hinged shell. Then a tug-of-war begins, with the tube feet pulling on the valves and the clam using all its muscular strength to keep its shell closed. Eventually the starfish, with its hundreds of tube feet, manages to create a small opening. A space only 1 mm or less is all that is needed for the starfish to eat the clam.

27-9 Feeding and digestion Just inside the mouth of the starfish is a thin saclike structure called the stomach. After a starfish pries open a bivalve, one region of the stomach turns inside out, moves through the thin opening between the valves, and surrounds the organs of the clam or oyster. Then enzymes are secreted, which kill and digest the victim. The softened material is then pulled

SCIENCE BACKGROUND

On the surface of the starfish are small pincers called pedicellaria that clean the epidermis. Extending from the surface are epidermis-covered spines from the endoskeleton and contractile dermal branchia, which are commonly called skin gills.

SCIENCE BACKGROUND

The tube feet are extended by the squeezing action of a muscular bulb. Contraction is caused by muscles in the foot that force water back into the bulb.

MAIN IDEA

The starfish digests the organs of bivalves by extending its stomach into the bivalve.



SCIENCE BACKGROUND

Not all starfishes are predators. Some live in the deep sea and eat ooze, digesting the organic material and eliminating the rest.

MAIN IDEA

Gas exchange in the starfish is through skin gills that are extensions of the coelom. Transport is by circulating coelomic fluid and amoeboid cells.

MAIN IDEA

Starfishes have a ring of nerves around the mouth. Radial nerves have a photoreceptor at the tip.

Bivalve mollusks, such as these mussels, are a favorite food of the starfish. Because of this, the starfish comes into conflict with humans.

inside where it is finally digested. It is then absorbed in a short intestine. The wastes are released through the anus, which is located on the top surface of the starfish disk.

27-10 Gas exchange and transport Gas exchange in the starfish occurs between the seawater and the **skin gills**, which are tiny fingerlike projections on the top surface of the starfish. The skin gills are thin-walled extensions of the coelom, which is filled with fluid.

The coelom itself is lined with ciliated cells that keep the coelomic fluid in constant motion. It is this movement of the coelomic fluid that is mainly responsible for transporting nutrients, oxygen, and wastes. Also in the coelomic fluid are amoeboid cells that move about and help transport certain wastes through the skin gills. The starfish does not have a circulatory system with blood vessels and a heart, like the mollusks.

27-11 Coordination The starfish has a very simple nervous system. It has one ring of nerves around the mouth. This nerve ring is connected to five radial nerves, one in each arm. At the tip of each arm is a photoreceptor. It is a simple eye that can detect light but probably not shapes or movements of objects.

27-12 Reproduction The sexes are separate in the starfish. Reproduction results after males and females release their sperm and eggs directly into the seawater, where fertilization occurs. The resulting fertilized egg then develops into an intermediate stage, which is a ciliated larva. This larva, which has bilateral rather than radial symmetry, swims around for several weeks. Then it settles to the bottom and develops into a small starfish.

The starfish has tremendous powers of regeneration. If a single arm with any part of the disk breaks off, it can grow into a whole new starfish.

27-13 Starfish as pests The commercial collecting and growing of bivalves, particularly oysters, is a major industry along the seacoasts of several countries. For the people in this industry, starfishes are often a problem. One starfish can eat up to a dozen oysters each day. Therefore the starfishes are in direct competition with the industry and they are looked upon as pests.

Several years ago a strong attempt was made to reduce the number of starfishes in certain clam and oyster beds. Many were caught and were broken into pieces in an effort to kill them. Imagine the surprise when it was discovered that regeneration had greatly increased the number of starfishes!

Now, one technique of combating the starfish pest is to scatter lime over the clam or oyster beds. The lime causes the outside layer of the starfish body to break down, and eventually the animals die.

27-14 Other echinoderms The largest group of echinoderms includes the brittle stars (class Ophiuroidea). These animals have a circular disk and slender, highly movable arms that are easily broken. The brittle stars have a great ability to regenerate new arms and often are observed with arms in the process of being regrown. The brittle stars are the most active of all echinoderms. They can sometimes be found in huge numbers in certain types of shallow water.

Another common echinoderm is the sea urchin (class Echinoidea), which is truly a spiny-skinned animal. The sea urchin has long spines sticking out from its body in all directions. It looks somewhat like a pin cushion. Some sea urchins release a poison from their spines that is painful to humans. A close relative of the sea urchin is the sand dollar, which has a flattened skeleton and short spines.

The sea cucumber (class Holothuroidea) is one of the weirdest of the echinoderms. Like the sea urchin, it has no

MAIN IDEA

Fertilization occurs in the water. The larvae have bilateral symmetry. Starfishes can also regenerate missing body parts.

MAIN IDEA

Starfishes are considered pests in clam and oyster beds. Breaking their bodies results in more starfishes. Lime causes them to die.

MAIN IDEA

Brittle stars, sea urchins, and sea cucumbers are other common echinoderms.

SCIENCE TERMS

water-vascular system
tube feet
disk
skin gills



ANSWERS TO CHECK YOUR FACTS

1. Their internal skeleton, radial symmetry, water-vascular system, and marine habitat.
2. When they are in the larval form.
3. The mouth is on the ventral side of the disc; the anus, on the dorsal side of the disc.
4. It is a network of closed tubes, or canals.
5. It is used for locomotion and for obtaining food.

ANSWERS TO REVIEW QUESTIONS

1. Gastropods: snail, slug; bivalves: oyster, clam; cephalopods: octopus, squid.
2. They both have a foot or a modification of one. They have a mantle and a well-developed respiratory system, and they are soft-bodied.

The brittle star (top left), the sea cucumber (top right), and the sea urchin (above) are all members of the phylum Echinodermata.

arms. But it has no spines either. It does have tentacles that surround the mouth and capture prey. The sea cucumber lies on its side in mud or slime and looks very much like the vegetable after which it is named. It is the most soft-bodied of all the echinoderms. Its internal skeleton is nothing more than microscopic particles of limestone scattered through the body wall.

CHECK YOUR FACTS

1. What are four characteristics of the echinoderms that distinguish them from other animals?
2. When do echinoderms show bilateral symmetry?
3. Where are the mouth and anus located in the starfish?
4. What structures make up the water-vascular system?
5. What are two functions of the water-vascular system?

SUMMARY

Phylum Mollusca is the second largest of all the animal phyla, with over 100 000 species. Most live in marine waters. They are characterized by a muscular foot, a mantle and the shell it produces, a well-developed respiratory system, and an efficient circulatory system. Members of phylum Echinodermata are all marine animals. They show radial symmetry as adults and have arms in multiples of five. They have an endoskeleton of limestone and a unique water-vascular system.

REVIEW QUESTIONS

1. Name three groups of mollusks and give examples of each.
2. List two things a snail and an octopus have in common that would support their classification as members of the same phylum.
3. What group of mollusks has a method of locomotion that resembles that of the starfish? Explain.
4. Describe how snails, clams, and squids obtain their food.
5. Suppose your job is to capture a squid alive. List adaptations of the squid that would make this task difficult.
6. What would you look for if you were trying to identify an animal as an echinoderm?
7. Describe the operation of the water-vascular system.
8. The starfish does not have a heart. How does it achieve its transport requirements?
9. How is digestion in the starfish vastly different from that in other organisms?
10. Name four echinoderms other than the starfish.

ANALYSIS AND APPLICATION

1. Mollusks form a large part of the fossil record. Can you guess why this is so? Which mollusks are the least likely to be found as fossils? Why?
2. The mollusks include several organisms with a size and mass much greater than anything found in more primitive phyla. What advances were necessary before such giant animals could exist?

3. The bivalves. They both extend an anchor and then pull the body toward it.

4. A snail extends its radula like a tongue to scrape plant matter and bring it into the mouth. The clam filters food from circulating water. The squid captures prey with arms covered with suckers.

5. The squid can escape by "jet propulsion" or by releasing ink into your field of vision. It can change its body color to blend with the surroundings, and it has a well-developed eye to warn it of your presence. If it is large enough, its ten arms might even make it difficult to give up and go home.

6. Spines on the body, radial symmetry with five arms or arms in multiples of five, tube feet, lack of a head, an internal skeleton, a marine habitat.

7. It is a network of canals that contains water under pressure. When muscular action increases the water pressure in an arm, hundreds of tube feet pop out, enabling the arm to grasp a solid surface.

8. Ciliated cells on the walls of the coelom circulate the coelomic fluid throughout the body. In addition, amoeboid cells aid in waste transport.

9. It is different because most digestion actually occurs within the body of the prey.

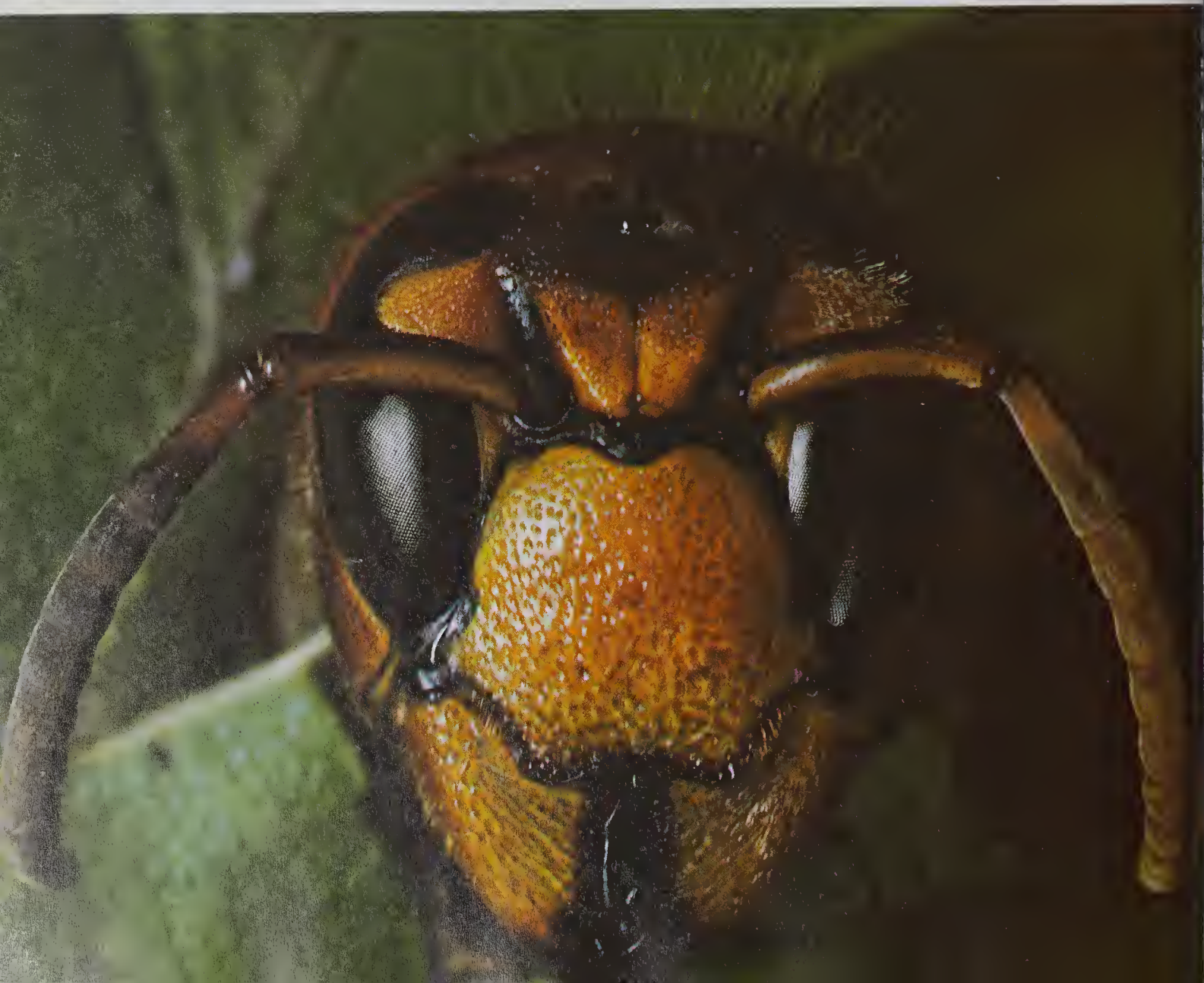
10. Brittle star, sea urchin, sand dollar, and sea cucumber.

ANSWERS TO ANALYSIS AND APPLICATION

1. Their shells are hardy enough to survive as fossils. Those without shells, because the soft parts would decay, leaving no record of them.
2. Well-developed respiratory and circulatory systems.

Investigations 44–45 from *Laboratory Investigations in Biology* can be done with this chapter.

28 *The*



OBJECTIVES

- To understand that the arthropods are the largest and most widely distributed of all the animal phyla
- To know that arthropods are unique in having segmented bodies with jointed appendages
- To appreciate that arthropods are successful, largely because of their tough chitinous exoskeleton
- To understand the nature of the arachnid body
- To describe the unique structure of crustaceans
- To explain the unique characteristics of the insect body
- To discuss the ways that insects undergo metamorphosis
- To appreciate the nature of the social insect society
- To understand some of the reasons the insects are among the most successful of all organisms

Arthropods

General Characteristics

28-1 The largest phylum The members of phylum Arthropoda are called **arthropods**, or “joint-footed animals.” Of all the phyla, this is the largest in number of species and in total number of animals. About 1 million different species of arthropods have been named and described. Many more species are probably yet to be discovered and classified. The arthropods include spiders, scorpions, ticks, lobsters, crabs, shrimp, millipedes, centipedes, and insects. The insects are, by far, the largest group of arthropods.

Besides their great number, the arthropods also are the most widely distributed group of animals. Arthropods are found at all levels in the oceans and on land from the poles to the tropics.

28-2 Segmented body and jointed appendages One general characteristic of arthropods is their segmented body. Many segments have jointed appendages that are flexible and adapted for a wide variety of functions. Some appendages are adapted for walking or swimming, which makes the arthropods much more mobile than most other invertebrates. Other appendages are adapted for such things as digging, clawing, grabbing, clasp- ing, making sound, pinching, carrying pollen, and holding eggs.

The arthropods also have a head that is greatly advanced over most other invertebrates. The head also may have a variety of appendages, which are usually adapted to food-

MAIN IDEA

Arthropods are the largest and most widely distributed of the animal phyla.

SCIENCE BACKGROUND

The largest arthropod is the Japanese crab (*Macrocheira*), which has a span of about 3.5 m.

The Rhinoceros beetle, shown below, is found in the United States from Connecticut west and south to Arizona.



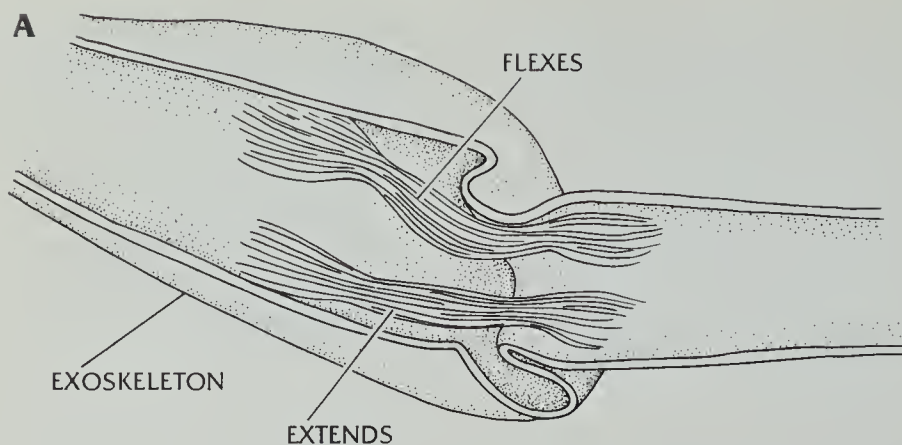
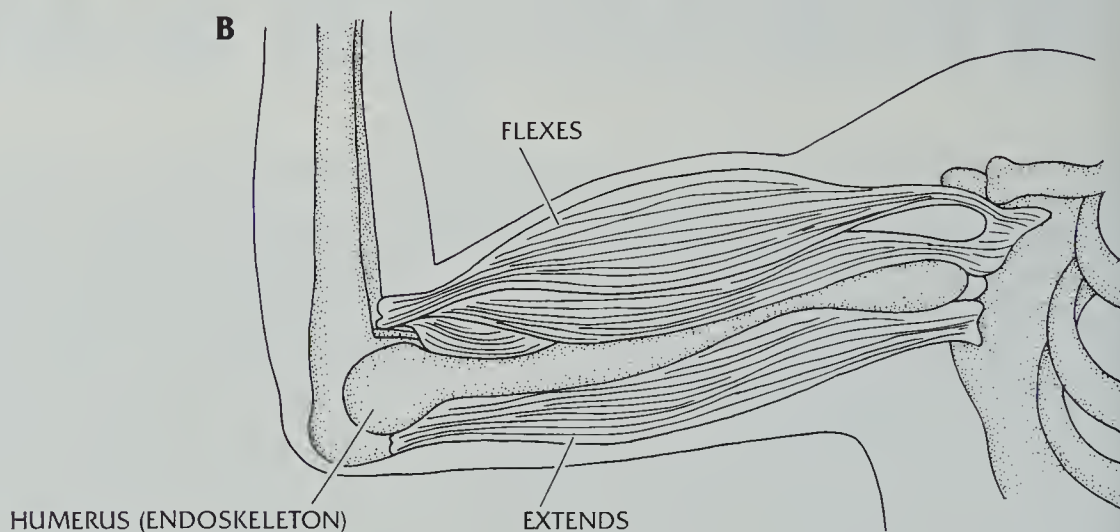


FIGURE 28-1

In arthropods the muscles are attached to the exoskeleton (A). In vertebrates the muscles are attached to the endoskeleton (B).



getting and feeding. The head is usually equipped with many different receptors. The arthropods are generally alert to things going on in their environment. This becomes obvious when you try to catch a housefly. The receptors, mainly in the head region, make it possible for the arthropod to be alert. This is one major reason why they are so successful.

MAIN IDEA

Arthropods have a tough chitinous exoskeleton that protects against damage and water loss and provides for muscle attachment. This exoskeleton is not flexible, and the arthropod must molt to grow.

SCIENCE TERMS

exoskeleton
chitin
molting

28-3 The exoskeleton Another major reason for the success of arthropods can be credited to their **exoskeleton** (ek sō skel'ə tən). The exoskeleton covers the outside of the body.

The arthropod exoskeleton is made of a tough, lightweight material called **chitin** (kī'tin). It performs three major functions. First, it is like a suit of armor and provides physical protection for the arthropod. Second, it provides a place for muscles to attach. The muscles provide the great mobility that gives arthropods a competitive advantage over most other animals. Third, the exoskeleton prevents the body from drying out, which is an important adaptation for living on land. To appreciate this function of the



exoskeleton, think what would happen if an animal such as the earthworm were to spend a summer day exposed to the hot sun.

The chitinous exoskeleton has one great disadvantage for arthropods. It will not stretch; therefore, it will not allow growth. In order for arthropods to grow, they must shed their exoskeleton several times by a process called **molting** (mōl'ting). After each molt, a second exoskeleton is already in place, but for a time it is soft and elastic. This is the time arthropods must grow and expand. The time of molting also is the most dangerous time for most arthropods. It is the time when they are the most inactive and therefore are the easiest to catch by predators. It is the time when they do not have their tough suit of armor to protect them.

CHECK YOUR FACTS

1. About how many species of arthropods have been identified?
2. List some structures that help make the arthropods so successful.
3. Why are arthropods more mobile than other invertebrates?
4. How is the arthropod head more advanced than those of most other invertebrates?
5. What is an exoskeleton? What is it made of in arthropods?
6. What are three functions of the exoskeleton?

The cicada shown in the photograph above is molting, or shedding its exoskeleton. Molting is necessary because the exoskeleton does not grow.

SCIENCE BACKGROUND

Chitin is a combination of protein and carbohydrate that is secreted by the epidermis. In some crustaceans the chitin is impregnated with calcium salts, which makes it even harder.

ANSWERS TO CHECK YOUR FACTS

1. About 1 million.
2. Their jointed appendages, highly sensitive receptors, and tough exoskeleton.
3. They have jointed appendages that are adapted for swimming or walking.
4. It has many specialized appendages and receptors.
5. A skeleton that covers the outside of the body. Chitin.
6. It provides physical protection, prevents the body from drying out, and serves as the site of muscle attachment.

The Arachnids

MAIN IDEA

The arachnid body consists of the cephalothorax and the abdomen. They have six pairs of appendages, four of which are walking legs. They have book lungs, and most have simple eyes.

SCIENCE BACKGROUND

Arachnid comes from the Greek word *arachné*, meaning "spider." Most arachnids are terrestrial animals, but a few are aquatic. (The fishing spider, which lives near the surface of freshwater ponds, is quite adept at catching small fish.) Other characteristics of the arachnids include the lack of antennae and mandibles, which are common on other arthropods. Tracheae, the breathing tubes of insects, are also found in arachnids; however, the book lungs—in aquatic forms, the book gills—are more important.

MAIN IDEA

Spiders are predators that kill their prey with poison injected through the chelicerae. Digestion occurs in the body of the prey.

SCIENCE BACKGROUND

The muscular pharynx is often called the sucking stomach.

28-4 General characteristics The arachnids (class Arachnida) include arthropods such as spiders, scorpions, ticks, and mites. Most of the arachnids are predators that are highly skilled at capturing and killing their prey. They are most common in warm climates, but they are seldom seen because of their habit of hiding in dark places.

One general characteristic of the arachnids is the way their body is divided into two regions. One region, called the **cephalothorax** (sef ə lō thôr'aks), is a combination of the head and the chest region, or thorax. The second body region is the **abdomen** (ab'də mən).

A second general characteristic of arachnids is their unique appendages. They have six pairs of appendages on the cephalothorax. The first pair is near the mouth and is called **chelicerae** (kə lis' ə rī). The chelicerae have sharp fangs on the end that are connected to poison glands. They are used to kill prey. The second pair of appendages is the **pedipalps** (ped'ə palps) and is also near the mouth. These are longer than the chelicerae. They help hold and sometimes crush the prey. The other four pairs of appendages are called **walking legs**, and they are farther back on the cephalothorax. By counting the walking legs, it is always possible to tell the difference between a spider or other arachnid from an insect. Arachnids have four pairs of walking legs. Insects have only three pairs.

Other general characteristics include a unique type of breathing organ called a **book lung**. There are two book lungs, which are a series of thin, flat cavities that open to the outside through the body wall. Blood is the main carrier of oxygen in the arachnids. Insects depend upon a completely different oxygen transport system, which is a network of air tubes.

Most arachnids have **simple eyes** that can detect moving objects but probably cannot see clear images.

28-5 The spiders The most commonly observed arachnids are the spiders, which are all predators. Some chase down their prey, some lay and wait to ambush them, but most trap their prey in silk webs that they make.

The feeding habits of spiders are typical of most arachnids. Once the prey is caught, it is killed by injections of poison through the chelicerae. The chelicerae also stab holes in the exoskeleton of the prey—usually it is another arthropod. Then digestive enzymes are secreted through the mouth, and the soft tissues of the prey are liquified. The liquid is then sucked into the stomach by a muscular



The wolf spider does not spin a web. It lives on the ground and pursues and captures its prey, mostly insects.

SCIENCE BACKGROUND

The term *cobweb* is usually used to describe irregular webs that form dense mats and collect dust and dirt in homes and other buildings.

pharynx. After the spider is finished, the prey may look almost alive, as if it were just resting in the spider web. Actually it is only the hollow exoskeleton that remains.

28-6 Spider webs Most spiders can spin webs that have a variety of uses besides catching prey. Some spiders line nests with the silk. Some females spin cocoons around their eggs. Young spiders often climb up on a high object and jump off, spinning a long thread of silk as they fall. Usually the wind catches this thread, and the young spider may be transported for a long distance. This behavior scatters the young spiders and decreases competition among them.

The webs are made from a protein substance produced in silk glands and ejected from the abdomen through fingerlike appendages called **spinnerets** (spin'ə rets). The protein is a liquid inside the body of the spider, but it turns to a solid when exposed to the air.

MAIN IDEA

Spider webs have several uses. They are produced in the silk glands and ejected through the spinnerets. Sensory hairs on the appendages detect vibrations in the web.



Most spiders spin webs. Insects that become stuck in the sticky threads will serve as a meal for the spider.

The most beautiful webs are spun by a group of spiders called orb weavers, of which the common garden spider is a member. The webs of the orb weavers are usually symmetrical and are made up of geometric patterns that are unique for each species. These webs are constructed of two kinds of silk. The radiating threads—those that go out in all directions from the center—are unelastic. They give the web its main strength. The spiral threads, which go around the center, are elastic and sticky and are the threads that mainly trap the prey.

Web-spinning spiders have sensory hairs on their appendages that detect the vibrations of animals caught in their web. This information also lets them know the size and strength of the victim.

MAIN IDEA

The black widow and brown recluse are two dangerous spiders found in Canada. Fatal spider bites are rare.

28–7 *Dangerous spiders* Most spiders perform a useful service by destroying insects that are a nuisance or are competitors with people. However, there are two dangerous spiders in Canada that can cause painful bites and, rarely, death.

One of the dangerous spiders is the female black widow. It was given this name because it was thought that she ate the much smaller male after mating. That seldom occurs, but it is a characteristic of several other spiders. The black widow is easy to recognize. It has a black body and a large, round abdomen with a red or orange hourglass figure on the ventral surface. It ranges from the southern reaches of Ontario all the way to British Columbia, but is most common in warmer climates. It is secretive and is usually found in dark corners of basements and garages. Its bite causes acute pain and other distress, which medical treatment with special injections can often relieve. Death occurs rarely from a black widow bite.

The second dangerous spider is called the brown recluse. It is brown and smaller than the black widow. This spider has a fiddle-shaped stripe on the dorsal surface of the cephalothorax. Like the black widow, the brown recluse prefers dark, protected places. Its bite produces destruction of tissue and a painful sore that is slow to heal. The bite is rarely fatal. Sightings of this spider have occurred in Ontario, in the southern regions of the province.

The black widow spider can be identified by the hourglass-shaped marking on its lower abdomen. The bite of this spider is dangerous.

SCIENCE BACKGROUND

The black widow toxin is a neurotoxin and affects blood calcium. One treatment is to inject a calcium compound. The toxin of the brown recluse is hemolytic, like that of the pit viper snake. It causes necrosis of tissue.

Some students may wonder whether the tarantula is a dangerous spider. It produces a painful bite, but it is not considered dangerous by zoologists.



MAIN IDEA

Scorpions, mites, and ticks are also arachnids. Mites and ticks have only one body segment and usually lack eyes.

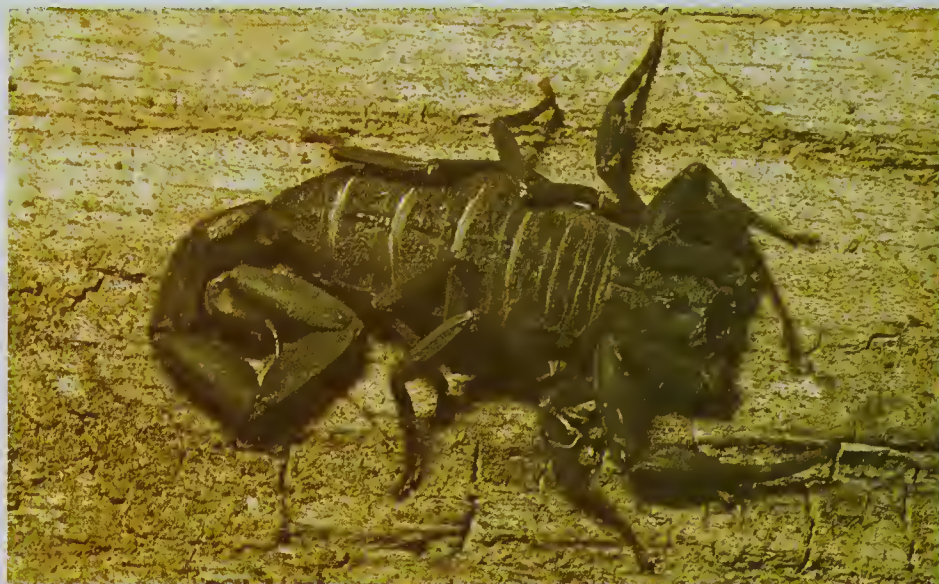
SCIENCE TERMS

cephalothorax
abdomen
chelicerae
pedipalps
walking legs
book lung
simple eyes
spinnerets

28-8 Other arachnids The scorpion is an arachnid with a long tail and a stinger. These relatives of the spider are active at night and live mostly in dry subtropical climates. Their sting is painful to humans, but they are not considered dangerous.

Ticks and mites belong to another arachnid group. They have the cephalothorax and abdomen fused into one region and are usually without eyes. Ticks suck blood from vertebrate animals and can swell to many times their normal size. The wood tick can carry a microorganism that causes Rocky Mountain spotted fever, a serious disease.

The scorpion uses its stinger to paralyze its prey, usually insects and spiders. Scorpions are most active at night.



Ticks (below left) are parasites that live by sucking blood. The red mite (below right) feeds on trees, crops, and other plants.



One kind of mite, which is much smaller than a tick, produces a troublesome larva. The larva is called a chigger. The chigger lives on the ground but attaches itself to human skin whenever possible. Then it secretes a digestive enzyme, which liquifies the skin and creates a tiny depression. The chigger sucks up the liquified tissue, and the irritation causes “chigger itch.”

CHECK YOUR FACTS

1. Describe the body segments of arachnids. Where are the appendages attached?
2. How many pairs of appendages do arachnids have? How many of these are walking legs?
3. What appendages are found near the mouth of a spider? What are they for?
4. What is a book lung?
5. How is oxygen transport in arachnids different from that in insects?

ANSWERS TO CHECK YOUR FACTS

1. The cephalothorax is a combination of the head and the chest, and behind this is the abdomen. On the cephalothorax.
2. Six. Four.
3. Chelicerae—used to kill prey, usually by injecting poison; and pedipalps—used to hold and sometimes crush prey.
4. A breathing organ unique to arachnids. It consists of a series of thin, flat cavities that open to the outside through the body wall.
5. In arachnids, blood carries oxygen. In insects, a network of air tubes is used to transport oxygen.

The Crustaceans

28–9 General characteristics The **crustaceans** (class Crustacea) are hard-shelled arthropods that include lobsters, crayfishes, shrimps, crabs, water fleas, and barnacles. This group is almost all aquatic, although a few live in moist terrestrial habitats. The exoskeleton of crustaceans is often harder than that of other arthropods because of limestone that is mixed in the chitin.

One general characteristic of most crustaceans is a pair of appendages on every segment of the body, including the abdomen. Arachnids and insects have no appendages on the abdomen. A unique characteristic of crustaceans is the presence of two pairs of **antennae** on the head. Most crustaceans also have a compound eye, which is a characteristic shared only by the insects.

Another characteristic of the crustaceans is their system for gas exchange. All crustaceans breathe through gills, even those that live on land. The gills have to be moist in order to function properly, and that is one reason why terrestrial crustaceans are always found in moist habitats.

28–10 The crayfish One of the most common freshwater crustaceans is the crayfish. It is found almost worldwide in rivers, ponds, lakes, and swamps. It lives on the bottom and sometimes digs burrows along the shore.

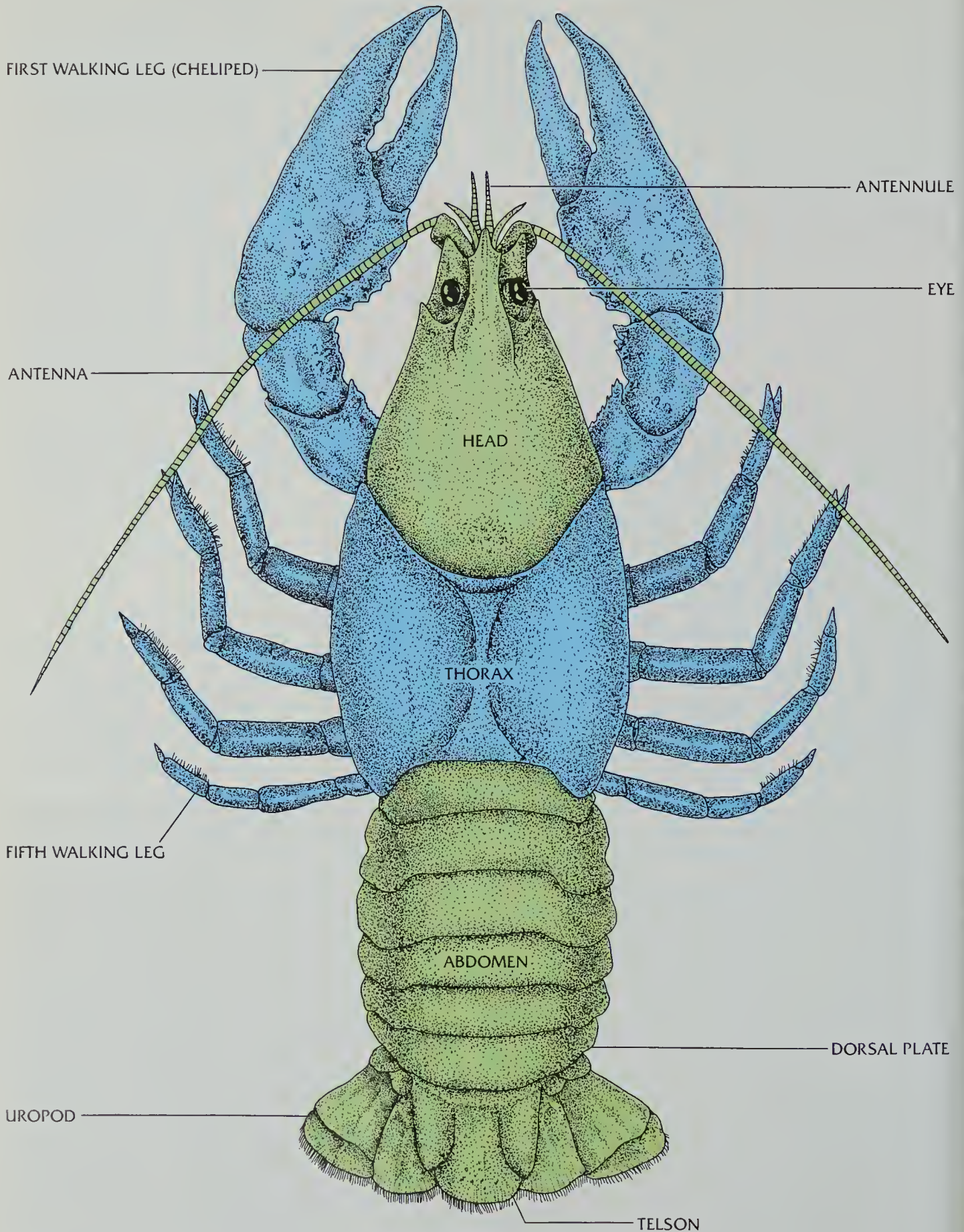
MAIN IDEA

Crustaceans are characterized by a pair of appendages on every segment, two pairs of antennae on the head, a compound eye, and gills; the chitinous exoskeleton usually contains limestone.

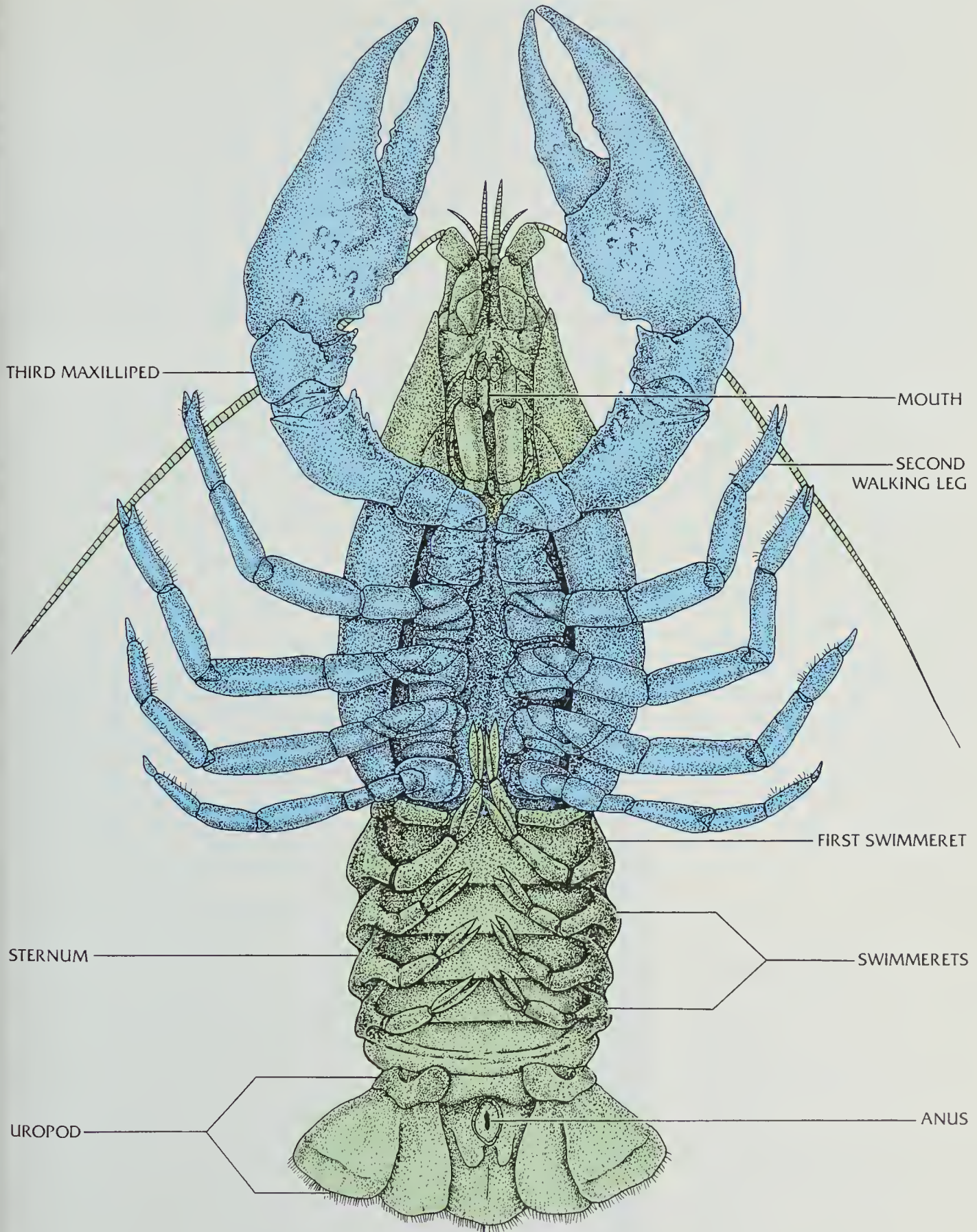
MAIN IDEA

Chelipids, mandibles, and the gastric mill function in digestion in the crayfish. A carapace protects the crayfish. Green glands function in excretion. Crayfishes have an open circulatory system.

DORSAL VIEW OF CRAYFISH



VENTRAL VIEW OF CRAYFISH



SCIENCE BACKGROUND

Some blind crayfishes are found in caves.

Crayfishes are mainly nocturnal and react negatively to light, with one exception—they react positively to the color red.

On a weight average basis, the grip of the cheliped is said to be 30 times more powerful than the human grip.

The gastric mill allows the crayfish to eat rapidly, then chew its food later when it is safely hidden.

The oxygen carrier in the blood is hemocyanin, which is a copper-containing respiratory pigment that functions like hemoglobin. The hemocyanin has a slight bluish color; when fully oxygenated in the laboratory, it is bright blue. Some crustaceans have hemoglobin as the oxygen carrier. Crustacean blood has powerful clotting agents, which make it possible for these animals to lose an appendage without much blood loss.

The green gland was once thought to be entirely an excretory organ. Now it is believed to be primarily an organ for maintaining osmotic control.

The crayfish abdomen, often called a crawdad tail, is highly prized as food. Crayfishes will eat almost any kind of food, alive or dead. They can swim backwards with amazing speed, by downward contractions of their abdomen. The crayfish differs only slightly from the lobster, which lives in marine waters.

Crayfishes catch their food with a pair of pincerlike appendages called **chelipeds** (kē'lə peds). The food is brought to the mouth by the chelipeds, then torn into smaller pieces by jawlike appendages called **mandibles** (man'də bəlz). However, the food is still not chewed or digested when it enters the mouth. Chewing occurs after the food reaches the stomach, in the **gastric** (gas' trik) **mill**. The gastric mill is made up of three teeth that are operated by muscles outside the stomach.

The anterior and middle regions of the crayfish are covered by a single large plate called the **carapace** (kar'ə pās). Beneath the carapace at the anterior end is a pair of compound eyes. Also there are two pairs of antennae. The compound eyes are made up of hundreds of photoreceptors, each with its own lens. The antennae have chemoreceptors for taste and smell, and mechanoreceptors to detect vibrations. Near the base of the antennae are special organs called **green glands**. The green glands are excretory organs and help control the water balance between the crayfish and its environment.

Underneath the back part of the carapace are the gills, which are delicate and featherlike. Gas exchange occurs between the water and the blood in the gills. Oxygen is transported by a carrier somewhat like hemoglobin, which is dissolved in the blood. When the crayfish stands in slow-moving or stagnant water, it uses certain appendages to create a current past the gills. This increases the amount of dissolved oxygen reaching the gills.

The circulatory system of the crayfish is different from that of the earthworm and of vertebrates like ourselves. It is an **open circulatory system**. The open circulatory system has a one-chambered heart, but the blood is only in closed tubes part of the time. When blood first leaves the heart, it is in closed vessels called **arteries** (ă'tər ēz). Arteries are vessels that carry blood away from the heart. But soon the arteries dump all the blood into open cavities called **sinuses** (sī'nəs ez). In the sinuses the blood bathes the tissues and supplies them with food and oxygen. Contractions of the body move the blood through various vessels to the gills and then to a sinus near the heart. The blood then flows into the heart through little openings with one-way valves.

28-11 Other crustaceans Some of the crustaceans are highly prized sources of human food. Major industries in many seacoast cities are devoted to catching lobsters, crabs, and shrimps.

Many crustaceans are very small or microscopic and make up much of the marine and freshwater **plankton** (plangk'tən). *Plankton* is the name for small aquatic organisms that either cannot swim or swim poorly. As part of the plankton, crustaceans are an important food source for fish and other aquatic animals.

There is one crustacean that was thought to be a mollusk for many years. This is the barnacle, which secretes a limestone shell around itself and cements itself to submerged objects. Once it is attached, it remains sessile and becomes a filter-feeder, like the clam and sponge. Barnacles create problems for ship owners because they attach to the bottom of ships. A heavy growth of barnacles can slow a ship by as much as 30 or 40 percent. They are such a problem that ships must sometimes be taken out of the water or dry-docked to have their barnacles scraped off.

The barnacles attached to this wooden post are exposed to the air during low tide. When submerged, the barnacles live as filter-feeders.



MAIN IDEA

Some crustaceans are prized as human food. Plankton contains many crustaceans. Barnacles are a problem for ship owners.

SCIENCE BACKGROUND

Terrestrial crustaceans that some students may have seen are sow bugs or pill bugs. An interesting terrestrial species is the coconut crab, which climbs coconut palm trees and knocks off coconuts to eat.

Some other crustacean pests are certain amphipods and isopods that bore into and damage submerged wooden piers and wharves. The Chinese mitten crab, a native of the Yangtze that has now spread to many waters, is a major problem in some areas because it bores into dams and embankments and undermines them. A catastrophic flood in Holland in 1953 is blamed on Chinese crabs that bored into dykes, causing them to weaken and fail.

SCIENCE TERMS

antennae
chelipeds
mandibles
gastric mill
carapace
green glands
open circulatory system
arteries
sinuses
plankton

ANSWERS TO CHECK YOUR FACTS

1. Because of limestone mixed with the chitin.
2. Appendages are found on the abdomen; two pairs of antennae are found on the head.
3. Chelipeds catch the prey and bring it to the mouth. Mandibles tear the prey into pieces. The gastric mill chews the food in the stomach.
4. A protective plate covering the anterior and middle regions of some crustaceans. Compound eyes. Gills.
5. They are excretory organs and help maintain water balance in the organism. At the base of the antennae.

MAIN IDEA

There are more species of insects than there are species of all other organisms. Entomology is the study of insects. Many insects are pests. Some are beneficial. They are adapted for life on land and for flight.

MAIN IDEA

Insects have three body regions. The head has mouthparts and compound eyes. The thorax has three segments, legs, and wings. The abdomen has spiracles and reproductive structures. The tracheal system functions in gas exchange. Insects develop by metamorphosis.

CHECK YOUR FACTS

1. Why are the exoskeletons of many crustaceans even harder than those of insects?
2. What structures found on the abdomen and the head of crustaceans are unique to this class?
3. Describe the function of the chelipeds, mandibles, and gastric mill in the crayfish.
4. What is the carapace? What structure is found under the anterior end of the carapace? The posterior end?
5. What do green glands do? Where are they located?

The Insects

28-12 The largest group of animals The insects make up the largest group of arthropods (class Insecta). In fact, there are more different species of insects than of all plants, protists, monerans, and other animals put together. About 800 000 different species of insects have been discovered and classified, and thousands more are expected to be found.

The specialized science of studying insects is called **entomology** (en tə mol'ə jē). Professional people who work with insects are called entomologists. At this time in our history, small armies of entomologists are at war against the insect world. With our exploding world population, the insects are having more and more effects upon human life. A great many insects compete with humans for the same food. Many, through their stings and bites, make human lives miserable. Some carry diseases, which can be fatal.

But some insects are helpful to humans. Many pollinate the plants that we depend upon for food. Others make honey and dyes that we prize. Several prey upon and destroy pests that would otherwise wipe out many of our farm crops and orchards.

Insects are mostly land animals. Some live in fresh water, but extremely few are found in marine waters. Insects are beautifully adapted for life on the land. Most are aggressive and can move quickly. Also most of them can fly, which gives them a tremendous advantage over their competitors, including humans.

28-13 General characteristics One general characteristic of insects is the division of their body into three regions. Insects have a distinct head, thorax, and abdomen.

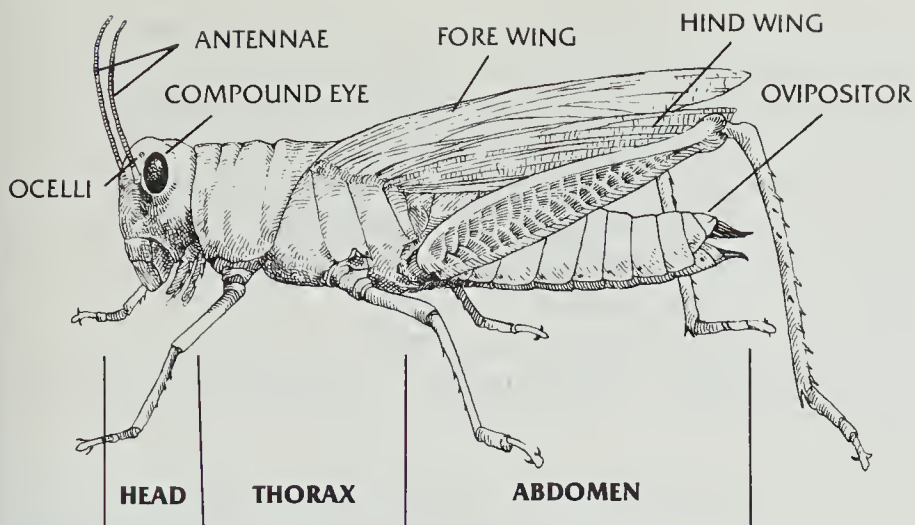


FIGURE 28-2 The general characteristics of the largest group of arthropods, the insects, are typified by the grasshopper.

The head region is equipped with one pair of antennae, which contain many receptors. Also the head has two compound eyes that are sometimes very large. In addition, many insects have two or more simple eyes. The major organs on the head are the **mouthparts**, which are highly specialized for food-getting. The mouthparts may be adapted for piercing and sucking animal or plant juices, for chewing, or for lapping liquids.

The thorax is the middle region of the body. It has three segments. Each of the three segments has a pair of walking legs. Also, on most adults, the last two segments each have a pair of wings. Only one major group of insects has less than two pairs of wings. The true flies—such as houseflies, horse flies, and mosquitoes—have only one pair of wings.

The abdomen is usually the longest part of the body. The abdomen of the adult is often partly covered with folded wings. Each segment of the abdomen usually has a small opening called a **spiracle** (spī'rə kəl). The spiracle functions in gas exchange, which will be discussed later. At the end of the abdomen there may be various kinds of structures used in reproduction. One example is the **ovipositor** (ō və poz'ə tər), which is a long hollow tube that some female insects use to bury eggs. A modified ovipositor forms a stinger in bees, wasps, and ants.

Another general characteristic of insects is their gas exchange system. It is called a **tracheal** (trā'kē əl) **system**. It consists of a network of branching tubes that carry oxygen directly to the cells and carbon dioxide away from them. The spiracles are the openings of the tracheal system, where gases enter and leave the body.

SCIENCE BACKGROUND

The sizes of insects range from 0.25 mm for certain beetles to 20–30 cm, the wingspan of some moths.

The tracheal system is very efficient, but it also imposes limitations on the size limit of insects. Contrary to science fiction literature, there will not be any monster insects. A large animal would have to have so many branches, with each branch being successively larger, that the animal would be made up mostly of hollow tubes.

SCIENCE BACKGROUND

The chemoreceptors on the antennae and other parts of the body are remarkably efficient. Certain male moths can detect odors from females several miles away.

SCIENCE TERMS

entomology
mouthparts
spiracle
ovipositor
tracheal system
metamorphosis
incomplete metamorphosis
naiad stage
gradual metamorphosis
nymph stage
complete metamorphosis
larva stage
pupa stage
social insects
queen
workers
drones
sclerotin

GRADUAL METAMORPHOSIS



FIGURE 28-3

In gradual metamorphosis the egg hatches into a nymph. The nymph grows and molts several times, eventually maturing into an adult.

MAIN IDEA

Most insects undergo the four stages of complete metamorphosis. Others go through incomplete or gradual metamorphosis. Both types have three steps.

SCIENCE BACKGROUND

Others that go through incomplete metamorphosis are the mayflies, stone flies, and grasshoppers.

Like the crayfish, insects have an open circulatory system. However, there are no capillaries, and the system is not as efficient as in the crayfish. If that seems strange in such a successful group as the insects, just remember one important fact. The circulatory system of insects does not have to furnish oxygen. A heart stoppage has little immediate effect upon an insect. Oxygen is supplied by an entirely different system, the tracheal system.

Another major characteristic of insects is that most of them go through different stages of development, called **metamorphosis** (met ə mōr'fə sis).

28-14 Types of metamorphosis Almost all insects go through one of three types of metamorphosis. One type, called **incomplete** (in kəm plēt') **metamorphosis**, is a three-stage pattern. The metamorphosis of the dragonfly is an example. The dragonfly begins life in an egg that is deposited in the water. That is the first stage. In the second stage, called the **naiad** (nā'ad) **stage**, the young dragonfly hatches from the egg and lives underwater, preying upon other aquatic animals. The naiad looks nothing like the adult that it will eventually become. The naiad has a short, squat body, with a huge mouthpart that is somewhat like a folded shovel with teeth on it. After several months of growth and molting, the dragonfly naiad crawls out of the water and molts again. But this time the creature that crawls out has a long, slender abdomen; four powerful wings; different mouthparts; and huge compound eyes. It is now in the third stage, the adult stage, and is a completely different animal.

The second type of metamorphosis also is a three-stage pattern. It is called **gradual** (graj'ü əl) **metamorphosis**. The development of the cabbage bug is a good example of this pattern. The cabbage bug begins life in the egg stage. When the egg hatches, the young bug enters the second stage, the **nymph** (nimf) **stage**. The nymph is almost exactly like the adult except that it is smaller, without wings, and sexually immature. The nymph grows and molts several times. Eventually it molts into an adult, which has wings and is sexually mature.

The third type of metamorphosis is a four-stage pattern. It is called **complete** (kəm plēt') **metamorphosis**, and is, by far, the most common pattern. Almost nine out of every ten insects go through complete metamorphosis. The beetle is a typical example. The beetle begins life in an egg. Then the egg hatches, and the second stage is the **larva** (lär'və) **stage**. The larva is like a worm except for the six legs on its thorax. The larva of a true fly has no legs

and is called a maggot. The larva grows and molts and eventually enters the **pupa** (pyü'pə) **stage**. The pupa stage is spent inside a protective case, or cocoon. In the pupa stage the insect undergoes the changes that will transform it into a completely different creature. After a time the case breaks open and the new creature, sexually mature and with wings, emerges as an adult.

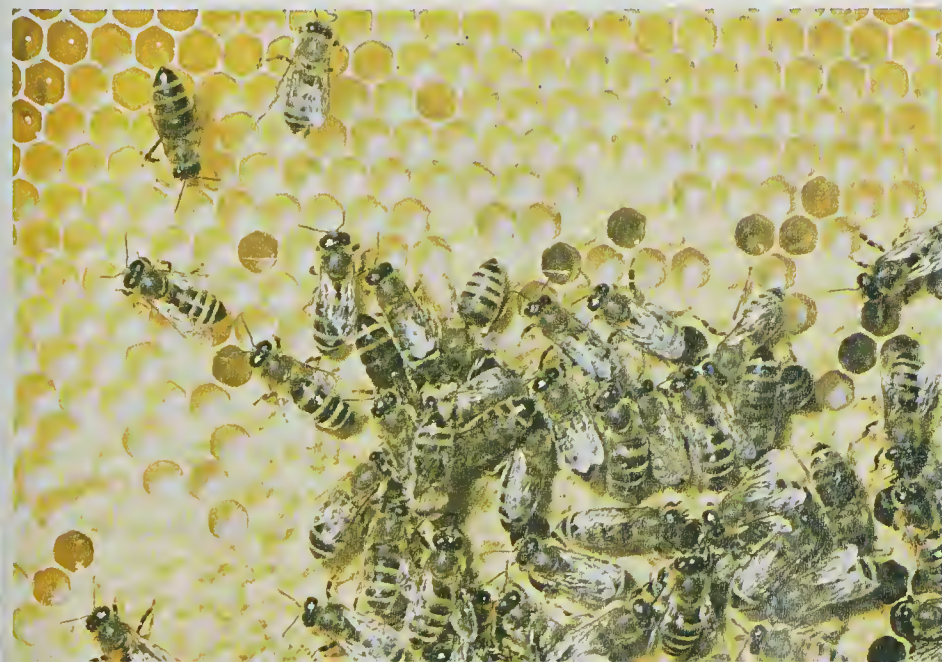
28-15 Social insects Most insects are free-living and a few are parasites. But some lead a way of life that is entirely unique among the invertebrate animals. Some insects, called **social insects**, form societies. The societies are like a cooperative community where all the adult activities are for the common benefit of all members.

The honeybee hive is an example of an insect society. In the hive there is a very specialized female called the **queen**, who lays all the eggs. Other, nonreproducing females, called **workers**, divide the other tasks. These include nursing the young, cleaning the hive, and searching for flower nectar and pollen. The males, called **drones** (drōnz), are much fewer in number. They provide sperm to fertilize the eggs.

Other social insects include the ants, certain other kinds of bees, and the termites.

28-16 Why are insects so successful? Almost anyone who studies insects for very long soon becomes an admirer of their great success. But why are they so much more successful than other animals?

The worker bees in a bee hive may care for the young, keep the hive clean, search for nectar, and defend the hive against invaders.



COMPLETE METAMORPHOSIS

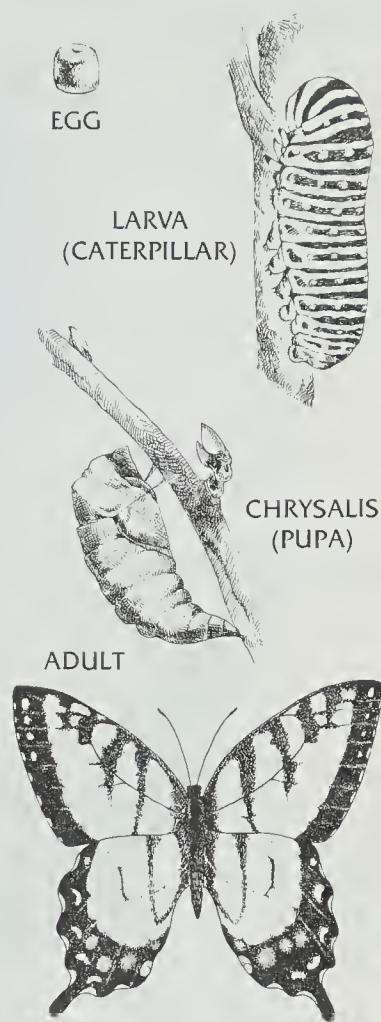


FIGURE 28-4

Most groups of insects, including the beetles, moths, butterflies, bees, wasps, flies, and ants, undergo complete metamorphosis.

SCIENCE BACKGROUND

A typical honeybee hive has 60 000 to 70 000 bees. The queen stores enough sperm during one mating to fertilize a million eggs. The queen may live for five years; workers live only a few weeks. Larvae can be made into queens by feeding them royal jelly, which is a secretion from the worker bees' salivary glands.

THE SIX LARGEST ORDERS OF INSECTS

CATERPILLAR
HUNTING BEETLE



LADYBIRD
BEETLE



ALFALFA
WEEVIL



ORDER COLEOPTERA, which includes beetles and weevils, is the largest order. These insects have two pairs of wings. The outer pair are thick and meet in a straight line down the back. The weevils have a long snout. This order undergoes complete metamorphosis.

TOBACCO
HORNWORM
MOTH



MONARCH
BUTTERFLY



SWALLOWTAIL
BUTTERFLY



ORDER LEPIDOPTERA includes moths and butterflies, which have two pairs of wings covered with hairlike scales. Moths have pointed antennae. Butterflies have an enlargement at the end of each antenna. The insects in this order undergo complete metamorphosis.

HONEYBEE



MUD DAUBER
WASP



ANT



ORDER HYMENOPTERA includes bees, wasps, and ants. These insects develop two pairs of membranous wings sometime during their life. Many insects in this order are "social insects." They undergo complete metamorphosis.

HOUSEFLY

MOSQUITO

CRANE FLY

ORDER DIPTERA includes flies and mosquitoes. These insects have only one pair of wings. This order includes important human pests that transmit diseases. The insects in this order undergo complete metamorphosis.

TARNISHED
PLANT BUGGREEN
STINKBUGCHINCH
BUG

ORDER HEMIPTERA has the only insects correctly called "bugs." These insects have two pairs of wings. The outer wings, which are partly membranous and partly leathery, overlap at the end of the back. Many insects in this order are plant pests. They use their sharp beaks to pierce plants and suck their juices. They all undergo incomplete metamorphosis.

GRASSHOPPER

KATYDID

CRICKET

ORDER ORTHOPTERA includes grasshoppers, crickets, and katydids. These insects have chewing mouth parts. Some are important plant pests. They have two pairs of leathery wings that fold straight over the back. They undergo incomplete metamorphosis.

ANSWERS TO CHECK YOUR FACTS

1. Entomology.
2. One pair of antennae; two compound eyes; perhaps two or more simple eyes; mouthparts.
3. It is the middle region of the body. It has three segments, each with a pair of walking legs. The last two segments each have a pair of wings except in the true flies, where there is only one pair of wings.
4. It is usually the longest region and is usually covered with folded wings. Each segment has a spiracle.
5. Gases enter the body through spiracles and travel to the cells in a network of tubes.
6. It does not have to provide the body with oxygen. Open.
7. Egg—naiad—adult.

ANSWERS TO REVIEW QUESTIONS

1. It protects the body from physical harm and from drying out. It also provides a place for muscles to attach. Its drawback is that it is not flexible, and the animal must shed its protective covering to grow.
2. A segmented body with jointed appendages. A two-segment body with four pairs of walking legs would be class Arachnida. A pair of appendages on every segment and two pairs of antennae would be class Crustacea. A three-segment body with wings and three pairs of walking legs would be class Insecta.
3. The arachnids usually have simple eyes. The crustaceans have compound eyes. The insects have a pair of compound eyes and many of them also have two or more simple eyes.
4. No. Arachnids use a breathing organ called a book lung. Crustaceans use gills. Insects use a unique tracheal system.

The nature of the insect exoskeleton helps explain their success. We said earlier in the chapter that the arthropod exoskeleton is made of chitin. In addition, the insect exoskeleton contains a material called **sclerotin** (skli' rət'ən). Sclerotin is a very tough material that is almost like leather. Also, on the outside of the exoskeleton, there is a thin layer of waxy material that waterproofs the exoskeleton. Together, the chitin and the sclerotin form a hard protective armor. The waxy material keeps the insect from losing its internal moisture. This combination in the exoskeleton makes the insect a very rugged animal, even in hot, dry desert climates.

A second reason for the great success of insects is their variety of adaptations for obtaining food. Just take one tree in a forest, for example. Some insects, such as aphids with piercing-sucking mouthparts, may be on the leaves, sucking the juices out. The same leaves may have: (1) caterpillars with mouthparts adapted for chewing off the outer layer of the leaf, (2) grasshoppers with mouthparts adapted for chewing off the edges of the leaves, (3) ants feeding upon honeylike secretions of the aphids, and (4) ladybird beetles eating some of the aphids. In addition, on some leaves a small gall wasp may be secreting a chemical that causes a tumorlike growth called a gall. The wasp lays eggs in the gall and the young larvae feed inside, protected and secure. On the flowers of the tree, several bees, wasps, and beetles may be collecting nectar and pollen. On the trunk of the tree, sawfly and wood-boring beetle larvae may be burrowing under the bark, feeding on the new tender layers of wood. The point of this example is that there are a tremendous number of different food sources in terrestrial and freshwater environments. The insects, more than any other group of animals, have adaptations for taking advantage of them all!

CHECK YOUR FACTS

1. What is the specialized science of studying insects called?
2. What structures are found on the head of insects?
3. Describe the thorax and its appendages. How can the true flies be identified by studying this body segment?
4. Describe the abdominal region of insects.
5. How do insect cells receive oxygen?
6. Why is the circulatory system less critical in insects than in other animals? Is this system open or closed?
7. What are the stages of incomplete metamorphosis?

SUMMARY

Phylum Arthropoda is the largest and most widely distributed of all the animal phyla. Species of class Insecta alone outnumber all other animal species. Arthropods are characterized by segmented bodies with jointed appendages. They feature a well-developed head with various types of receptors and mouthparts. Arthropods have a tough exoskeleton that protects them well, except during molting when they must shed their covering in order to grow.

REVIEW QUESTIONS

1. In what ways is the chitinous exoskeleton advantageous to arthropods? How is it a disadvantage?
2. By what structures would you be able to identify an arthropod? How would you know to which class it belongs?
3. What type of eyes are characteristic of each of the three classes of arthropods?
4. Are the methods of gas exchange similar among arthropods? Explain.
5. Compare the ability of arachnids to find sources of food with that of insects. Which of these classes of arthropods has diversified more?
6. How does the composition of the exoskeleton vary among the arthropods? How do these differences affect its characteristics?
7. Briefly describe the types of metamorphosis seen in insects. Which is most common?
8. What are social insects? Describe the society in the honeybee hive.
9. How are insects an enemy to people? How do they benefit people?
10. Why are the insects so successful?

ANALYSIS AND APPLICATION

1. If a pesticide used on grasshoppers kills by suffocation, what structures would it probably affect?
2. Although the compound eyes of insects are not as advanced as your own eyes, they do have one important advantage over the camera eye. What is it?
3. Of all the major habitats in the world, insects have failed to adapt to one of them. Can you name the habitat that insects have failed to adapt to?

5. Arachnids are very efficient predators and they are primarily dependent on this manner of obtaining food. The insects, however, have adapted to fill almost every imaginable niche.

6. In crustaceans, limestone is often mixed with chitin to form an exoskeleton that is harder than those found in other arthropods. Insect exoskeletons contain, in addition to chitin, sclerotin, which helps make the exoskeleton very tough.

7. See section 28–14.

8. Insects that form societies where all adult activities are for the common benefit of all the members of the population. The queen bee lays all the eggs. The other females are workers; they divide the non-reproductive tasks among themselves. The males are drones and provide sperm to fertilize the eggs.

9. They compete with people for food; they bite and sting; and some carry deadly diseases. They benefit people by pollinating plants that we use for food, destroying pests, and producing things like honey.

10. They are alert, agile, quick, and aggressive. They have adaptations that aid in food-getting, in attack and defense, and in survival in harsh conditions. They have a tough and watertight exoskeleton. They are very mobile, especially those that can fly. They reproduce very efficiently. They can occupy several niches as they go through the stages of metamorphosis.

ANSWERS TO ANALYSIS AND APPLICATION

1. The spiracles.
2. They provide a much wider field of vision.
3. Insects have not successfully adapted to living in the oceans.

UNIT 5 REVIEW

1. List some characteristics of animals that distinguish them from plants.
2. Prepare a sketch of the body plan of a typical sponge and label the main structures.
3. Discuss the methods of reproduction found in sponges.
4. What are the general body characteristics of coelenterates that distinguish them from most other groups of animals?
5. Sketch a typical hydra and label the important bodily features.
6. What advances have flatworms made over coelenterates? What advances have roundworms made over flatworms?
7. While the earthworm is the most familiar member of the phylum Annelida, most of the members of this phylum are aquatic. Prepare a report on the life cycles and habitats of several types of marine annelids.
8. List the general characteristics of the phylum Mollusca.
9. The octopus has the undeserved reputation of being a dangerous creature. Write a report on the nature, habits, and habitat of the octopus.
10. What are the functions of the tube feet in starfishes?
11. Why are starfishes considered pests by people in the shellfish industry?
12. Some species of spiders do not spin webs. Prepare a report on a species of spider that does not spin a web, concentrating on how it captures its prey.
13. Why are crustaceans considered arthropods?
14. Discuss the various types of metamorphosis that occur in insects.
15. Many studies have been done on communication among members of a bee colony. Specifically, a bee that has located a source of nectar seems able to indicate to other hive members the direction and the distance of the nectar from the hive. Prepare a report on how bees are able to communicate this information.
16. Discuss reasons why insects are so successful as a group.



Unit 6

ANIMALS WITH BACKBONES

The vertebrate animals all have either a backbone or a structure that is considered to be the primitive model of a backbone. The main groups of vertebrates are the fishes, the amphibians, the reptiles, the birds, and the mammals. The fishes are the dominant animals in all the waters of the earth. The amphibians try to bridge the gap between life in the water and life on land. The reptiles are scaled animals that once dominated all other forms of life on the land. The birds are feathered flyers. The mammals, our own group of animals, have hair and nurse their young with milk. The vertebrates are the most advanced and most intelligent organisms on the earth.

Investigations 46–48 from *Laboratory Investigations in Biology* can be done with this chapter.

29 *Fishes and*



OBJECTIVES

- To name the characteristics that chordates share
- To appreciate that nearly all chordates are vertebrates and that the vertebrates have a unique body structure
- To name the three main groups of fishes
- To understand the unique circulatory and respiratory systems of the fishes and how they work
- To discuss the basic nature of amphibians and why they are poorly adapted for life on land
- To name the basic kinds of amphibians

Amphibians

The Fishes

29-1 Introduction to phylum Chordata The most complex and most advanced animals belong to the phylum Chordata. These include fishes, amphibians, reptiles, birds, and mammals.

The members of phylum Chordata, called **chordates**, have unique characteristics. They all possess a **notochord** (nō'tə kōrd) at some stage in their life. The notochord is firm, yet flexible, and extends the length of the body. It is a supporting structure that stiffens the body. However, in most chordates the notochord is present only during periods of embryonic development.

Another unique characteristic of chordates is the presence of a **dorsal** (dōr'səl) **nerve cord**. This nerve cord is the main trunk line for nerve impulses. It runs the length of the body and lies above the digestive tube. Usually the dorsal nerve cord is enlarged at its anterior end to form a brain.

The third characteristic of chordates is the presence of **gill slits**. Gill slits are openings in the pharynx that extend through the body wall and to the outside environment. In many chordates the gill slits are present only during early embryonic development.

29-2 Subphylum Vertebrata Almost all the chordates belong to subphylum Vertebrata and are called vertebrates. The vertebrates have all the chordate characteristics. But they also have some unique characteristics of their own. The notochord, for example, often is not pres-

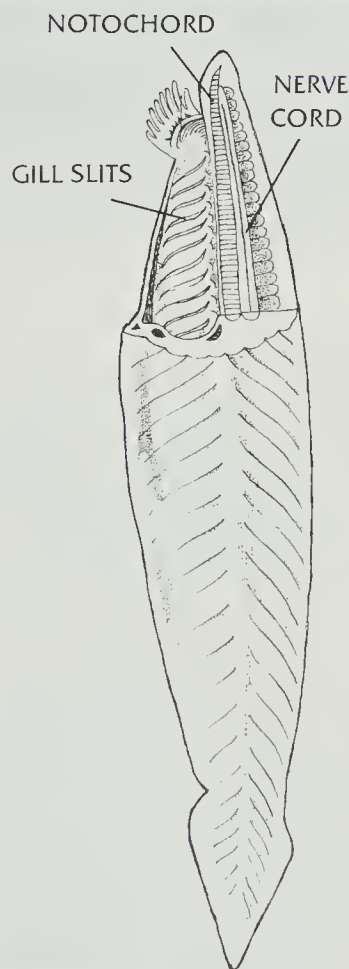


FIGURE 29-1

Amphioxus is not a vertebrate but it is a member of phylum Chordata. The notochord, gill slits, and dorsal nerve cord identify it as a chordate.

SCIENCE BACKGROUND

Chordata comes from the Greek word *noton*, meaning "black," and the Latin word *chorda*, meaning "cord."

The dorsal nerve cord of chordates lies above the digestive tube; the nerve cord of invertebrates is ventral and below the digestive tract.

ent in adult life. It is replaced by a **vertebral** (vēr'tə brəl) **column**. The vertebral column is a chain of cartilage or bone vertebrae. The vertebrae surround the dorsal nerve cord and provide support, yet flexibility, for the body.

Another characteristic of vertebrates is their skin, or **integument** (in teg'yū mənt). The integument has two layers. The outside layer is the **epidermis**. The **dermis** is the inside layer. There are many specialized parts of the integument to be found on vertebrates. These include scales, claws, feathers, horns, fingernails, and hair.

All vertebrates have a well-developed **endoskeleton** (en dō skel'ə tən). This endoskeleton differs in one important way from the exoskeleton of arthropods. The endoskeleton of vertebrates is alive and capable of growing with the animal. The exoskeleton of arthropods is non-living and must be shed in order for growth to occur. The living material of the vertebrate endoskeleton is cartilage or a mixture of cartilage and bone or mostly bone. An important part of the endoskeleton is the protective case for the brain, which is called the **cranium**.

Most vertebrates also have two pairs of appendages. Examples of vertebrate-paired appendages are fins, legs, flippers, and wings. The snakes are a well-known exception, but even they have paired appendages during certain stages of embryonic development.

MAIN IDEA

Fishes are the largest group of vertebrates. They are successful because they have excellent sensory and breathing organs and have adapted to obtain every kind of available food.

29-3 The fishes There are five major groups of vertebrates: fishes, amphibians, reptiles, birds, and mammals. The largest group is the fishes with more than 22 000 species, which is more than the other four groups combined.

The fishes are a very successful group of animals. Like the insects, they have adaptations for obtaining every kind of food that is available in their environment. In addition, they have excellent sense organs that enable them to be alert and to react quickly to any challenge. They obtain their oxygen through highly specialized gills. Fish gills are the most efficient breathing organs found in any animal.

MAIN IDEA

The jawless fishes include the lampreys and hagfishes. The sea lamprey is a parasite that almost destroyed the game fish in the Great Lakes.

29-4 The jawless fishes The members of one small group of fishes are sometimes called fishlike animals by zoologists. This group of fishes are the jawless fishes (superclass Cyclostomata), which include the lampreys and hagfishes.

The lampreys are the best known of the jawless fishes. They lack jaws but have a suckerlike mouth surrounded by teeth. Also their bodies are long, rounded, and snakelike in structure. Unlike most other fishes, they have no scales on their body.



The sea lamprey has a suckerlike mouth for attaching to the body of a host fish. Using its teeth, it gnaws into the tissue and sucks blood.

The sea lamprey is a parasite and probably is the most hated fish in North America. Years ago it invaded the Great Lakes and killed most of the lake trout and many other fish. The sea lamprey kills other fish by first attaching itself to the fish's body with its suckerlike mouth. Then it cuts holes with its sharp teeth and sucks out the blood, with the help of an anticoagulant that it secretes. At one time the sea lamprey had almost destroyed game fishing in some of the Great Lakes. Now fishing is improving, partly because of programs to reduce the size of the sea lamprey population.

29–5 The cartilage fishes Another group of fishes includes the cartilage fishes (class Elasmobranchii). The members of this group total about 3 000 species of sharks and rays.

As the name suggests, the cartilage fishes have an endoskeleton of cartilage. Other characteristics include a set of jaws with many teeth. Their integument is also covered with tiny teeth that extend out from their scales.

SCIENCE BACKGROUND

The hagfishes are exclusively marine and are scavengers, often eating fish that have been netted by anglers before they can be hauled in. They bite into the body of a fish and eat the insides, literally leaving skin and bones. When caught, the hagfishes secrete copious amounts of a slimy mucus.

MAIN IDEA

The cartilaginous fishes include sharks and rays. Sharks have a streamlined body and a variety of fins. Rays are mostly bottom-dwellers. Some rays produce an electric shock to paralyze their prey.

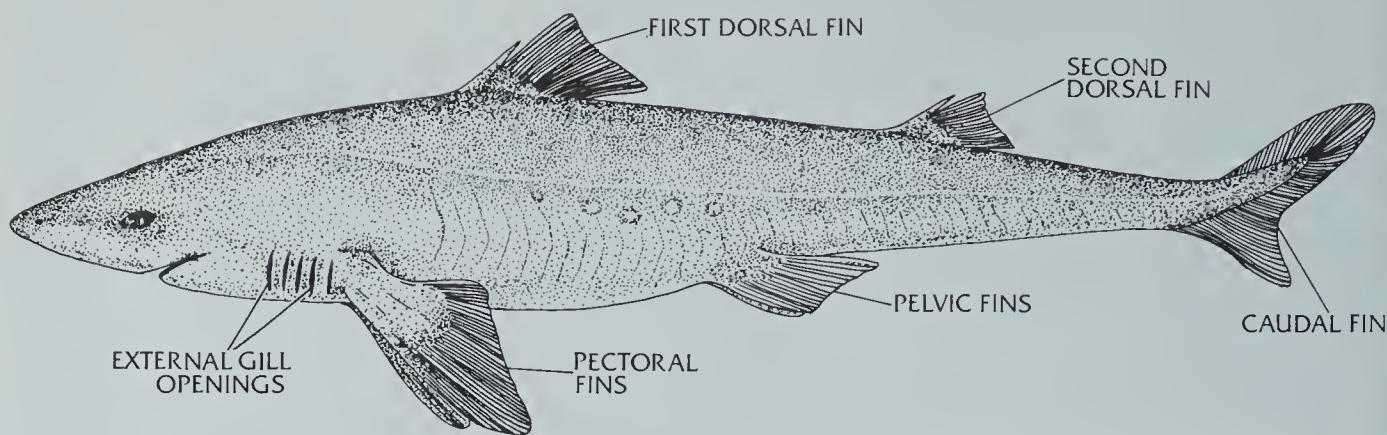


FIGURE 29-2 The general body form and positions of the fins in a typical shark are shown in the illustration above.

SCIENCE BACKGROUND

Often the vertebrae of sharks and rays are calcified and appear to be bony.

The sharks are the better-known cartilage fishes. They have a streamlined body with a variety of fins. They have a pair of **pectoral** (pek'tər əl) **fins**, which are near the gill slits. Also they have a pair of **pelvic** (pel'vik) **fins**, farther back on the body. In addition, they have two **dorsal fins** and a nonsymmetrical **caudal** (kô'dəl) **fin**. The fins are used primarily for steering purposes as the shark swims through the water.

The largest fish, and the second largest of all animals, is the whale shark. It grows up to 15 m long and may weigh as much as 18 000 kg. Fortunately for swimmers and divers, its feeding habits are like that of the blue whale, which is the largest of all animals. Both feed on plankton and are harmless to humans.



Most sharks, such as this white-tipped reef shark, are predators. Some species, such as the great white shark, will attack humans.



Rays are mostly bottom-dwelling fishes. Their pectoral fins are greatly enlarged and look like wings. Actually they function somewhat like wings. The rays flap their enlarged pectoral fins up and down, and this motion propels them through the water.

Some rays, such as the electric ray, produce electric shocks that can paralyze their prey. Also the electric shocks can be dangerous to humans. However, the largest ray, the manta ray, looks very dangerous but is a harmless plankton-feeder, like the whale shark.

29-6 The bony fishes The great majority of fishes are the bony fishes (class Osteichthyes). They have a skeleton mostly of bone, and their integument is usually covered with scales. The catfish is an example of a bony fish without scales.

The yellow perch is common in fresh water and has the typical external structure of other bony fishes. It has paired pectoral and pelvic fins, large dorsal fins, and a symmetrical caudal fin. Also, like most bony fishes, it has an **anal fin**.

The fins of the bony fish often have strong bony rays, which are small bones that support the fins and give them rigidity. The rays also may be modified into sharp spines and used for protection. The catfish is an example of such a fish. Also a certain species of catfish, called the walking catfish, uses its pectoral fins for another purpose. It walks on them. It does this when it leaves one body of water and walks to another.

A unique characteristic of the bony fishes is the **operculum** (ō pēr'kyə ləm) that covers the gills. The gills themselves are very efficient. They may take as much as 80 percent of the oxygen out of the water that flows over them.

The diet of a sting ray includes crustaceans, shellfish, and bony fish. The tail spine of the sting ray contains a poison dangerous to humans.

MAIN IDEA

Most fishes are bony fishes. Most have scales and an anal fin. They have an operculum and a swim bladder. The swim bladder enables bony fishes to remain at any depth without swimming.

The operculum and gills are easily visible in this eastern brook trout. The presence of an operculum is unique to bony fishes.



SCIENCE TERMS

notochord
dorsal nerve cord
gill slits
vertebral column
integument
epidermis
dermis
endoskeleton
cranium
pectoral fins
pelvic fins
dorsal fins
caudal fin
anal fin
operculum
swim bladder

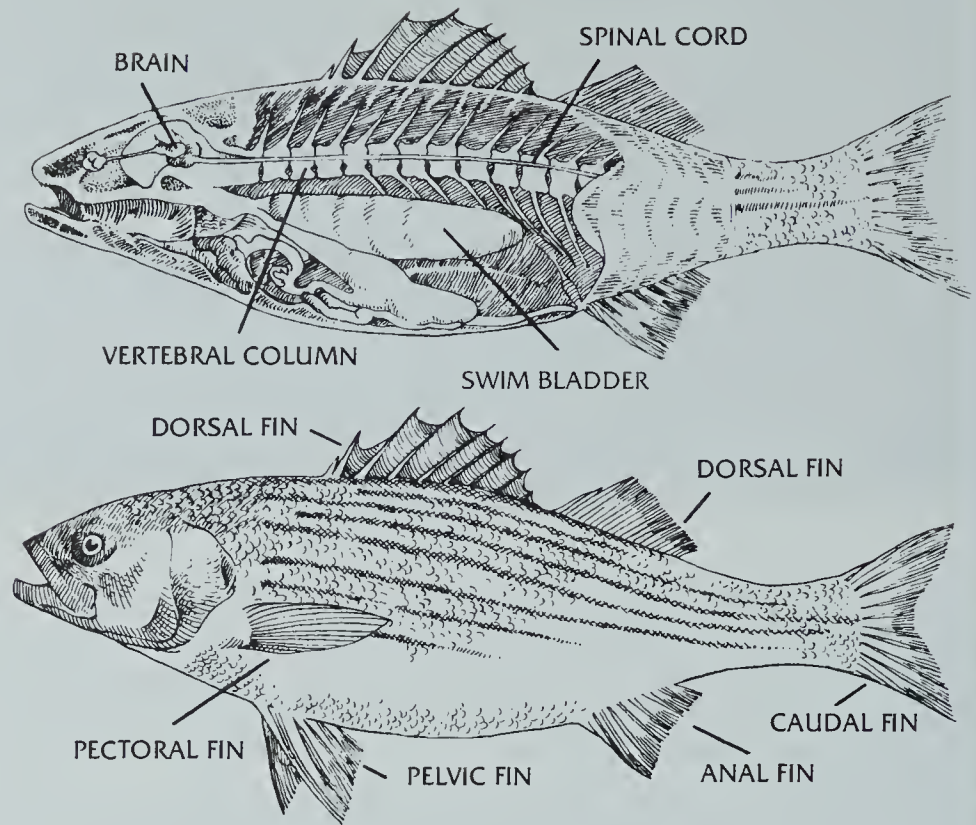


FIGURE 29-3 A simplified illustration of the internal and external anatomy of a typical bony fish is shown above.

SCIENCE BACKGROUND

Many zoologists use the term *gas bladder* rather than *swim bladder*.

MAIN IDEA

Fishes have a closed circulatory system with a two-chambered heart. Fishes reproduce sexually, with development occurring either in the water or in the female.

Another unique characteristic of bony fishes is an organ called the **swim bladder**. This organ contains air, and by controlling the amount of air in the swim bladder, the fishes can remain at any depth without swimming. This allows them to save energy. Sharks do not have swim bladders. Therefore, sharks must constantly swim forward or else they will sink.

29-7 Other functions The fishes, like all vertebrates, have a closed circulatory system, which uses hemoglobin as the oxygen carrier. The fishes have a two-chambered heart that pumps blood through arteries, veins, and capillaries.

The fishes reproduce sexually. The usual pattern is for the female to lay eggs in the water and for the male to deposit sperm over them. The young fishes then hatch in the water.

Another reproductive pattern is for the eggs to be fertilized internally. Then the young develop inside the female, using the yolk of the egg for food. After they are developed they pass out of the female's body; thus the female gives birth to living young. This same pattern of development also occurs in certain amphibians and reptiles.

CHECK YOUR FACTS

1. What are the three distinguishing characteristics of the chordates?
2. What is a notochord? What are gill slits?
3. What additional structures do members of subphylum Vertebrata share?
4. What makes up the vertebrate integument?
5. In what major way is the vertebrate endoskeleton an advancement over the exoskeleton of arthropods?
6. What distinguishes the class to which the shark belongs from other fishes?

The Amphibians

29–8 Problems on the land The **amphibians** include such animals as frogs, toads, and salamanders. Their name means “double life,” which is a way of describing how they often live. Many amphibians spend part of their life in water and part of their life on land. However, the amphibians are not very successful land animals when compared with the insects or the birds and mammals that we shall study later.

In at least three ways, living on land is more difficult than living in water. One problem is related to the relative weight of an animal in water and on land. An animal weighs less in water than on land. Therefore body support is not the problem in water that it is on land. Land animals of any size need a strong skeleton to support their body. A second problem has to do with the temperature of the environment. Most water environments have a uniform temperature, with only small changes. But temperatures on land can vary drastically, especially from season to season.



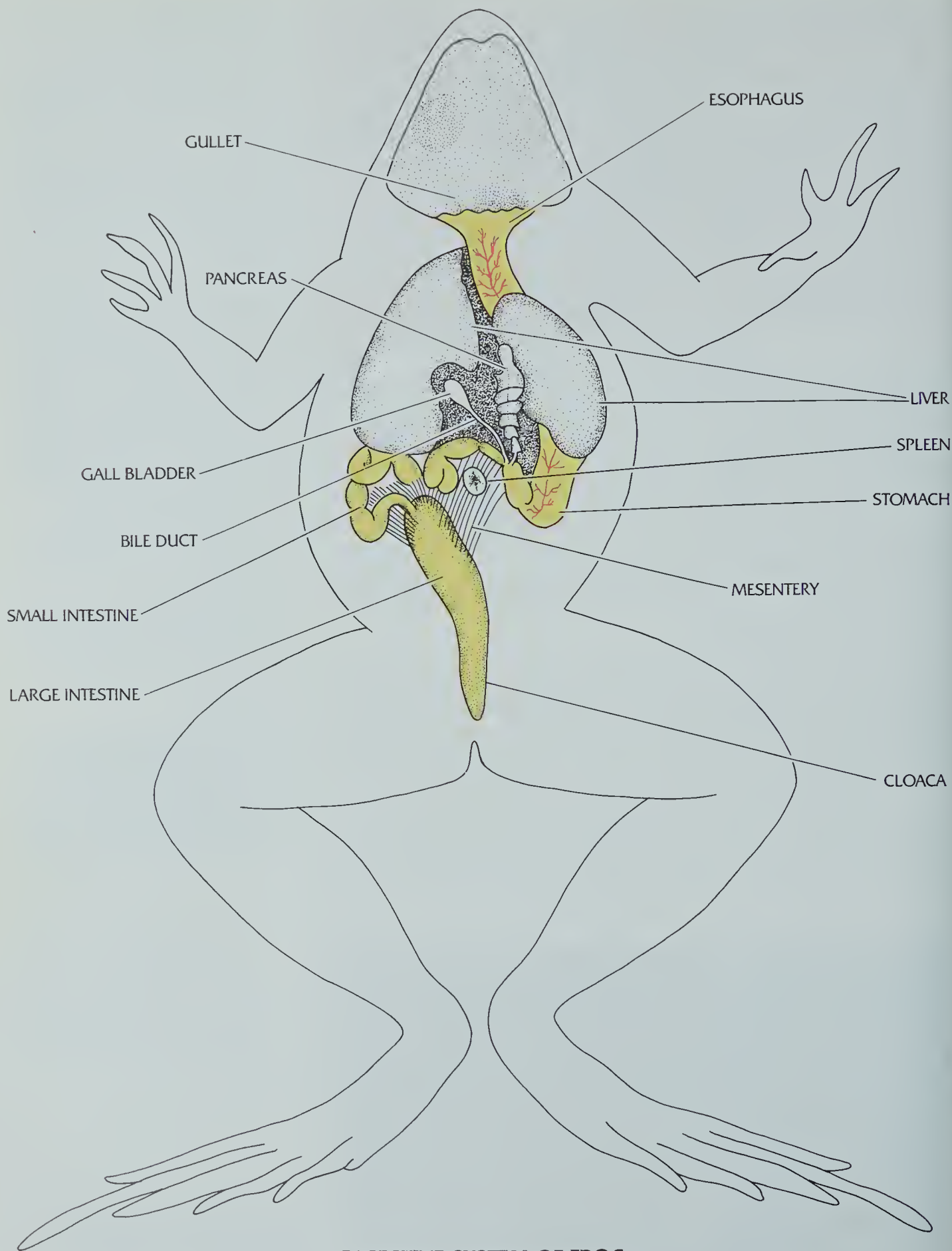
ANSWERS TO CHECK YOUR FACTS

1. The presence of a notochord, a dorsal nerve cord, and gill slits.
2. A flexible supporting structure that extends the length of the body. Gill slits are openings in the pharynx that extend through the body wall to the outside.
3. A vertebral column, a two-layered integument, a well-developed endoskeleton that includes a cranium, and usually a pair of appendages.
4. It consists of the dermis, or inner layer; the epidermis; and various specialized parts such as hair, feathers, or claws.
5. It is living tissue that can grow with the animal, thus avoiding the need for molting in order to grow.
6. It has an endoskeleton of cartilage, jaws with many teeth, and teeth on the integument.

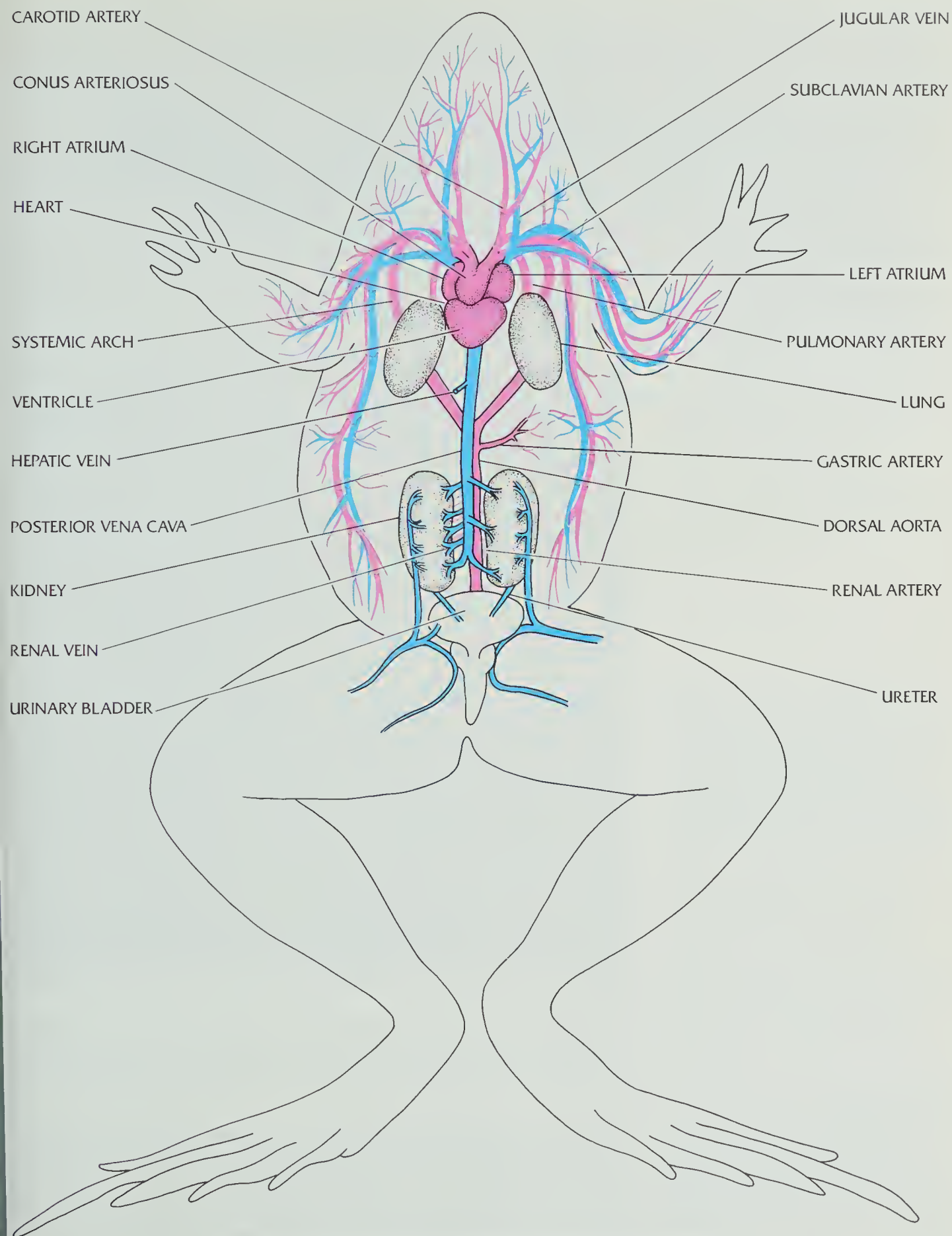
MAIN IDEA

Amphibians have a strong skeleton, but they are poorly adapted for life on the land because they are cold-blooded and cannot retain water. This limits their choice of habitat.

The mud puppy is totally aquatic and retains external gills as an adult. However, it also has lungs.



DIGESTIVE SYSTEM OF FROG



CIRCULATORY AND EXCRETORY SYSTEM OF FROG

SCIENCE BACKGROUND

Living on the land also has some advantages over living in water. There is usually 20 times more oxygen in air than in water. Most land habitats also offer more secure shelters and safer places to leave eggs and the young.

There is a third group of amphibians, the caecilians, which are blind limbless amphibians found in South America, Africa, and some islands in the Indian Ocean. They live in moist soil or in water.

MAIN IDEA

Most adults have two pairs of legs. They breathe through lungs, gills, and skin. They have a double circulatory system with a three-chambered heart.

MAIN IDEA

Salamanders number only about 230 species. They have tails. Though many live on land, nearly all reproduce in the water.

A third problem of living on land is the need to avoid excess loss of body water by evaporation.

The amphibians have done a good job of solving only one of the above problems. They have a strong bony skeleton that provides support for their body.

Amphibians are not well adapted for surviving wide changes in the temperature of their environment. They are **cold-blooded**, which means that their body will assume the same temperature as that of the environment. This is not a problem when the temperatures are warm. Life functions do well at warm temperatures. However, body functions slow down or stop at low temperatures. This limits the habitats and seasons where amphibians can live and be active. They cannot be active during cold winter months and they cannot live at all in the polar regions.

The integument of amphibians is permeable to water, and they have only limited adaptations to keep them from drying out by evaporation. Most of them live in moist habitats where the evaporation rate from their body is reduced. Also most are **nocturnal** (nok tēr'nəl), which means that they are active at night. During the day they are usually found under plants, logs, or stones. Their main adaptation is the production of mucus by special glands in the integument. The mucus coats the body and helps prevent water from evaporating through the skin.

29-9 General characteristics Most adult amphibians have two pairs of legs, which are used for locomotion. The legs of salamanders are about equal in size. The legs of frogs and toads differ in size, with the hind legs much longer and adapted for jumping. The presence of legs is a key adaptation for living on land, and a major advancement over the fishes.

A second major characteristic of the amphibians is their ability to breathe by three different methods. Those that live in water usually breathe with gills. On the land, amphibians breathe through the skin, and with lungs. The presence of lungs is another major adaptation for living on land.

A third major characteristic of amphibians is a double circulatory system, with a three-chambered heart as the pump. This circulatory system will be discussed later.

29-10 The salamanders One main group of amphibians is called the tailed amphibians (order Urodela). This is a relatively small group of about 230 species, most of which are found in North America. Salamanders live on water or on land. Most that live on land return to the water



The eastern tiger salamander (above) burrows in soft ground and breeds in small ponds. The leopard frog (left) breeds in ponds and lakes. While it is often found in ponds, at times it ranges into fields and meadows.

SCIENCE BACKGROUND

Although the presence of lungs is a major characteristic of the amphibians and an advancement over lower animals, most amphibians rely more upon gas exchange through the skin.

Authorities also believe that terrestrial amphibians cannot breathe with the lungs alone but must rely upon the skin. Frogs that hibernate in the mud of ponds must rely exclusively upon skin breathing for what little oxygen their body needs.

MAIN IDEA

The integument of frogs and toads may contain mucous glands, poison glands, and chromatophores. The latter allow the organism to change its color.

to reproduce. The typical salamander is about 15 cm long. The largest salamander, the Japanese giant salamander, reaches a length of 1.5 m.

29-11 Frogs and toads The largest group of amphibians is the group that includes the frogs and toads (order Anura). The adults of this group do not have tails. The frogs vary the greatest in size. One species is small enough to fit on the top of a dime. The largest frog is a West African

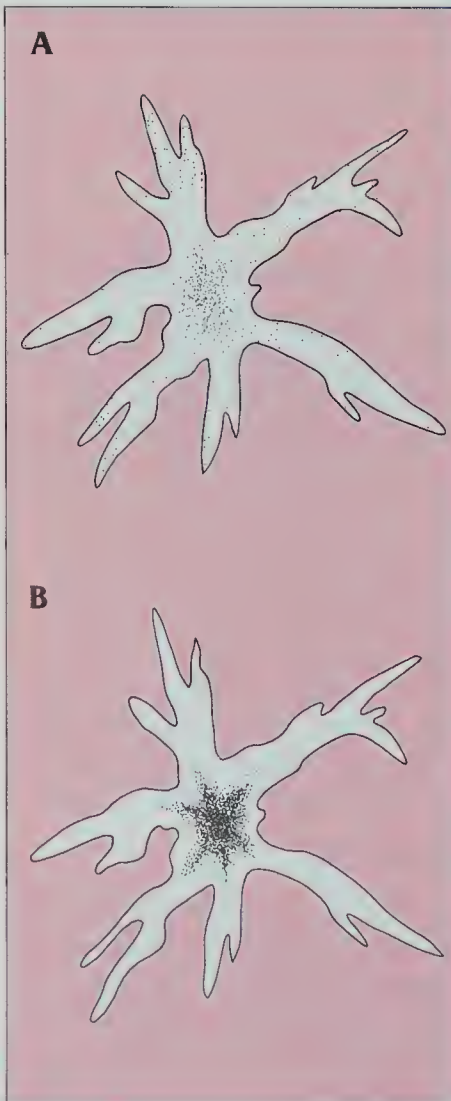
SCIENCE BACKGROUND

The name *Salientia*, rather than *Anura*, is often used for the order containing the frogs and toads.

About 50 percent of the frog species are tree frogs, which are highly adapted for such life with suckers on their feet and coloring that blends with their habitat.

FIGURE 29-4

A chromatophore can either scatter its pigment, giving the skin a dark appearance **(A)**; or concentrate its pigment, giving the skin a light appearance **(B)**.



In tree frogs the tips of toes are usually expanded into sticky disks that aid the frog in moving about on limbs and branches.

species with a body (not counting legs) up to 30 cm long.

The integument of frogs is usually thin and slimy. Toads, which often live in drier habitats, have a rough integument covered with bumps, or “warts.” For both animals the integument has several protective functions. It has mucous glands, which help prevent water loss from the body. Many frogs and toads have poison glands in the integument that help to protect them from predators. In addition, the integument may contain **chromatophores** (krō’mə tō fōrz), which are specialized cells that contain different pigments. Each chromatophore can concentrate or scatter its pigment, thus changing its color from dark to light. With

all the chromatophores working together, the animal can change color to blend in with its surroundings. This helps it remain hidden from its enemies.

29-12 The double circulatory system The term *circulatory system* is used to describe a transport system where the blood flows in a continuous route. For example, the circulation in fishes is from the heart to all parts of the body and back to the heart.

In amphibians and in more advanced vertebrates the blood takes two circulatory routes. One route, called the **pulmonary** (pul'mə nər ě) **circulation**, is from the heart to the lungs and back to the heart. The pulmonary circulation allows gas exchange to occur in the lungs, with the blood gaining oxygen and losing carbon dioxide.

The second route is called the **systemic** (sis tem'ik) **circulation**. In this route blood flows from the heart to all parts of the body, then back to the heart. The primary function of the systemic circulation is to carry food and oxygen to all the body cells, and to carry away their wastes.

The amphibian heart has three chambers. Blood from the lungs enters the **right atrium** (ā'trē əm). Blood from the body enters the **left atrium**. Next, the blood in both chambers flows into the **ventricle** (ven'trə kəl), the bottom chamber. Here there is probably some mixing of the blood that is rich in oxygen and the blood that is low in oxygen. From the ventricle the blood is then pumped out of the heart, with some going to the lungs and some going to the body.

The amphibian heart is not considered to be an efficient pump. This is because blood that is rich in oxygen is mixed in the same chamber with blood from the body. The four-chambered heart of more-advanced vertebrates is much more efficient. The four-chambered heart has two

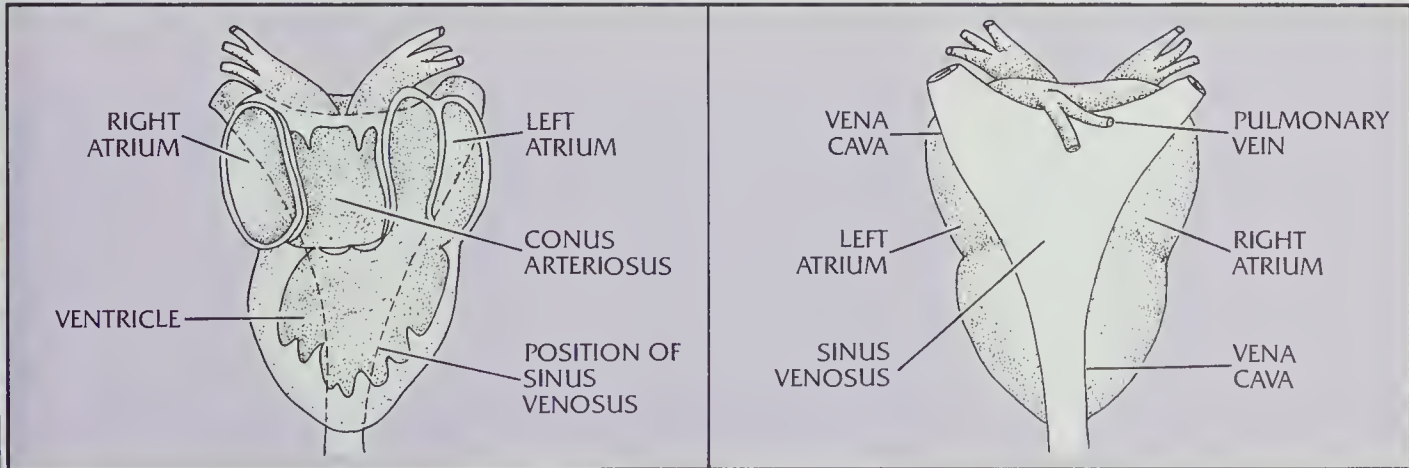
MAIN IDEA

Amphibians and higher vertebrates have a systemic and a pulmonary circulation. Some mixing occurs in the single ventricle of the amphibian heart.

SCIENCE TERMS

- cold-blooded
- nocturnal
- chromatophores
- pulmonary circulation
- systemic circulation
- right atrium
- left atrium
- ventricle

FIGURE 29-5
The figure below shows the structure of the frog heart in dorsal and ventral views. The frog's heart has only three chambers.



ANSWERS TO CHECK YOUR FACTS

1. Because the name means "double life," which describes how these animals live—partly in the water, partly on the land.
2. When an organism lives on land, support of body weight, regulation of body temperature, and the prevention of excessive water loss all become problems that must be solved or avoided.
3. Not very well. They have a good structural skeleton, but they can do little to adjust their body temperature or prevent water loss.
4. In a cold-blooded animal the external temperature will determine the body temperature.
5. They live in moist habitats, avoid direct sunlight, are usually nocturnal, and secrete mucus that coats their skin and reduces water evaporation from the skin.

ANSWERS TO REVIEW QUESTIONS

1. A notochord, gill slits, and a dorsal nerve cord. Only the dorsal nerve cord.
2. They have a vertebral column, a two-layered integument, a well-developed endoskeleton, and usually two pairs of appendages.
3. Fishes, amphibians, reptiles, birds, and mammals. Fishes.
4. Class Osteichthyes—the bony fishes. They usually have scales and an anal fin. They have a bony skeleton, bony fins, an operculum, and a swim bladder.
5. They are heavier than water and they must expend energy to maintain a certain depth. In most fishes a swim bladder acts like an air-filled balloon and allows the fish to remain at a certain level.
6. A pair of pectoral fins near

ventricles, where blood from the lungs and blood from the body are separated.

29–13 Feeding and digestion Adult amphibians are carnivores, which means that they eat other animals. Frogs and toads will eat about any kind of animal that they can catch or swallow. Many are equipped with a tongue that is sticky on the end and attached near the front of the mouth. They can shoot this tongue out and catch their prey, and they are often fast enough to catch flying insects. They have no teeth in their jaws and cannot chew their food. They may have a few teeth in their throat, but these just help keep their prey from escaping before they can be swallowed.

The digestive tube of the adult frog and toad consists of a stomach that is easily stretched and a short intestine. Carnivores always have a shorter digestive tube than herbivores, which are plant eaters. Plant matter requires more time for digestion.

29–14 Reproduction and metamorphosis Frogs, like most amphibians, lay eggs in the water, where they are fertilized. During early development the eggs are enclosed in a jellylike capsule. After about a week a tiny tadpole breaks out of the jelly and begins an independent life. It swims with its tail, breathes through gills, and feeds on plant matter. The tadpole continues to grow and eventually develops two pairs of legs. Then it loses its tail and takes the form of an adult frog. Thus there is a complete change of body form, which is the process called metamorphosis. During metamorphosis internal changes have also occurred. Lungs have developed, gills have disappeared, and the long digestive tube of the plant eater has shortened to that of a carnivore.

The larval stage of most frogs is called a tadpole. It is an aquatic organism and breathes with gills.



CHECK YOUR FACTS

1. Why is the name *amphibian* an appropriate one?
2. In what ways is life on land more difficult than life in water?
3. How well have the amphibians adapted to the problems of living on land?
4. What do we mean by *cold-blooded*?
5. How do frogs avoid losing excessive water?

SUMMARY

The most complex and advanced animals are those in phylum Chordata. Chordates, at some stage in their development, possess a notochord, a dorsal nerve cord, and gill slits. Almost all chordates belong to subphylum Vertebrata. These animals have a vertebral column, an integument, a well-developed endoskeleton, and usually two pairs of appendages.

REVIEW QUESTIONS

1. What structures are present at some stage of development in all chordates? Which of these are present in an adult frog?
2. How are vertebrates different from other chordates?
3. What are the five major groups of vertebrates? Which has the largest number of animals?
4. To which class do most fishes belong? How can they be identified?
5. Why must sharks swim forward constantly to avoid sinking? How have most fishes overcome this problem?
6. Describe the arrangement of fins on the shark.
7. Compare the circulatory systems of fishes and amphibians.
8. Trace the path of blood through the amphibian heart. Why is this inefficient?
9. Describe metamorphosis in frogs.
10. Are amphibians truly successful land animals? Explain.

ANALYSIS AND APPLICATION

1. If cold temperatures drastically affect the ability of amphibians to function, how can we explain the ability of some fishes to live in icy mountain lakes and streams?
2. Why, do you think, have fishes developed breathing devices that are more efficient than those of the other vertebrates?

the gill slits; a pair of pelvic fins, farther back on the body; two dorsal fins; and a caudal fin.

7. Fishes have a two-chambered heart, and the blood follows the equivalent of systemic circulation. A three-chambered heart in amphibians pumps blood through both a pulmonary and a systemic circulation.

8. Blood from the lungs enters the right atrium; blood from the body enters the left atrium; both chambers empty into the ventricle from which blood is pumped out to both the lungs and the body. It is somewhat inefficient because oxygen-rich blood is mixed with oxygen-poor blood. Mixed blood is sent to the lungs and to the body.

9. Eggs are fertilized in open water. Eggs develop in a jelly-like capsule until the tadpole is formed. The tadpole swims with a tail, eats plant matter, and breathes through gills. Then it loses its tail and develops legs. The gills are replaced by lungs, and the digestive tube shortens. An adult frog is formed.

10. No. They are cold-blooded. They have hardly any adaptations to prevent water loss and are thus confined (usually) to moist habitats.

ANSWERS TO ANALYSIS AND APPLICATION

1. These fishes have adapted to the colder temperatures. Since the temperature remains within fairly constant limits, the organism is not dealing with the problem the frog has, which is really one of variance not of temperature.

2. Air contains about 20 times more oxygen than water. Greater efficiency is more critical to aquatic animals than to land animals.

30

The Reptiles



OBJECTIVES

- To appreciate that the reptiles were the dominant animals for about 100 million years of the earth's history
- To explain why the reptiles are much better adapted to life on land than the amphibians are
- To understand the basic differences between the major groups of reptiles

30-1 Past masters of the earth How long is 100 million years? If you try counting to 100 million by thousands, you will discover that 100 million is a very large number. Yet that is the number of years that the reptiles were the dominant animals on the earth. The most famous reptiles of that period were the huge dinosaurs. But the fossil record shows that there were thousands of other reptiles that were not as large as the monsters we see in museums. There were aquatic reptiles, creeping reptiles, reptiles that ran on their hind legs, and even reptiles that could fly. They were abundant almost everywhere.

About 60 million to 80 million years ago, the reptiles started to die out. The decline occurred over several million years, but when measured by geologic time, it occurred rapidly. Now, millions of years later, only a few of the original reptiles remain. Some of these are nearly identical to fossils that are over a hundred million years old. The survivors include lizards, snakes, turtles, crocodiles, alligators, and a rare "living fossil" called the tuatara.

30-2 General characteristics The reptiles have several characteristics that are advances over the amphibians. They have a thick exoskeleton of dry scale, which sometimes has bony plates underneath. They also have the normal vertebrate endoskeleton. The exoskeleton helps prevent water loss from the body, an adaptation that makes the reptiles better suited for living on land than the amphibians. Reptiles have few, if any, mucous glands in their integument. Contrary to popular belief, there is no such thing as a "slimy" snake.

MAIN IDEA

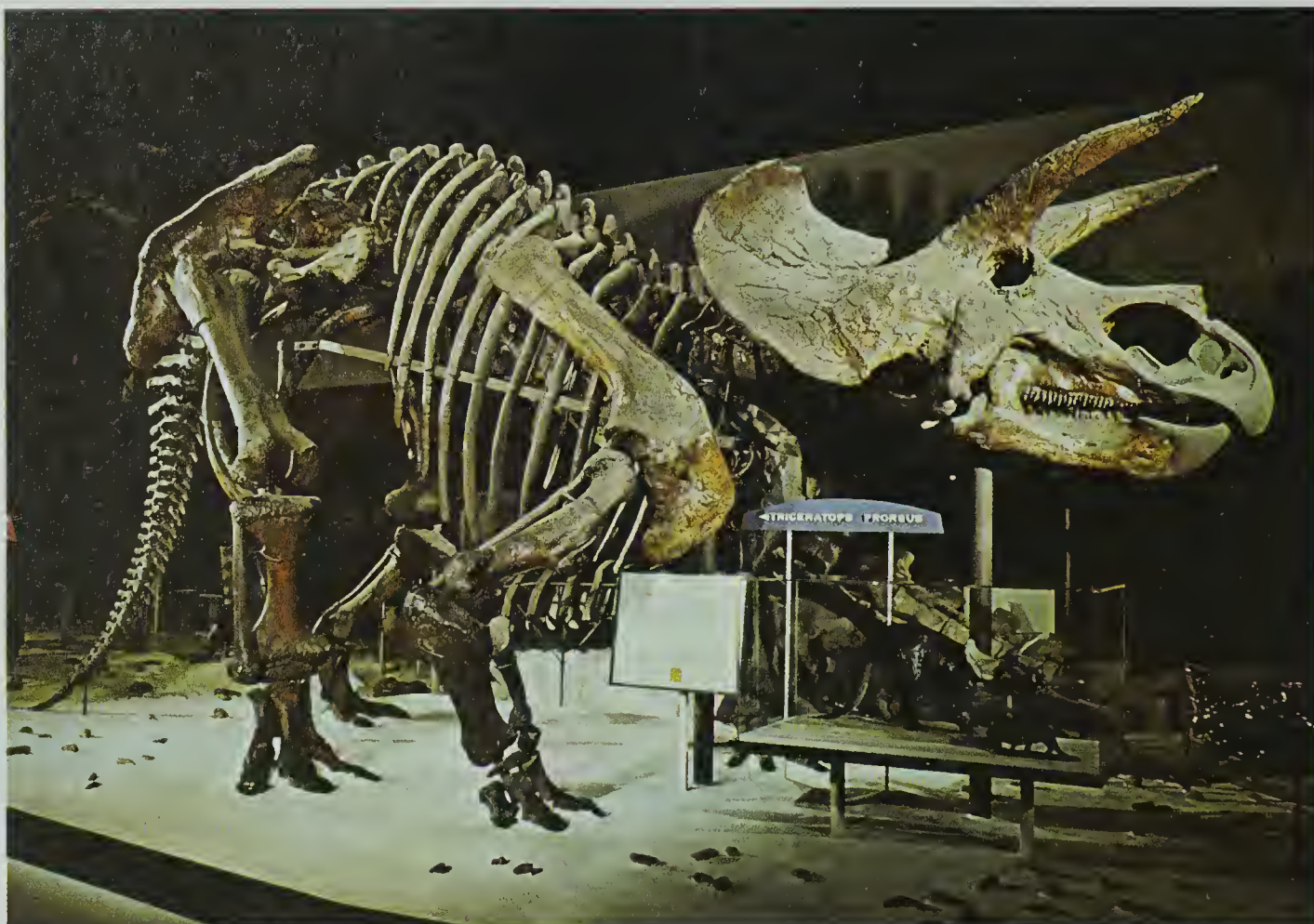
Reptiles were the dominant animals for about 100 million years. They began to die out about 60 million to 80 million years ago, and only a few remain today.

SCIENCE BACKGROUND

The reptiles were the first terrestrial animals. They appeared in the Paleozoic Era and dominated the Mesozoic, which is sometimes called the Age of Reptiles. Paleontologists continue to debate the cause of the "sudden" decline of the reptiles. At the time they were declining, modern land plants were becoming established and mammals were present.

MAIN IDEA

Reptiles are much better adapted to life on land than the amphibians. Their heart is superior. Their egg allows them to reproduce on land.



The most famous and fascinating reptiles were the dinosaurs. The formidable-looking Triceratops, shown above, was a plant-eater.

SCIENCE BACKGROUND

Even in the crocodilians there may be some mixing of arterial and venous blood through the foramen of Panizzae, which is a tiny opening between the two aortas that carry blood away from the ventricles.

The reptilian egg is more correctly called an amniotic egg. It has the four membranes that give it its physiological qualities.

Many reptiles have two pairs of legs, usually with toes and claws. The snakes and some lizards are exceptions. The legs give many reptiles a speed advantage over other animals. The toes and claws give some reptiles great climbing ability, which allows them to live in trees.

All reptiles breathe with lungs, even aquatic reptiles such as crocodiles. None have gills, and skin breathing is rare.

The reptile heart is more efficient than the heart of the amphibian. Most reptiles still have a three-chambered heart, but there is a partial wall in the ventricle. This helps prevent the mixing of blood from the lungs with blood from the body. In alligators and crocodiles there is a complete wall that divides the ventricle, making a four-chambered heart.

Zoologists consider the reptile egg to be the main adaptation that enabled reptiles to have such great success as land animals. The reptile egg is always laid on land. It is covered

with a leathery or calcified shell that resists drying. It has a large yolk, which provides plenty of food for the developing young. The reptile egg has made it possible for these animals to roam all over the land and to lead a life mostly independent of water. Unlike the amphibians, the reptiles have never had to return to the water to reproduce.

30-3 Lizards The lizards belong to the same major group of reptiles as the snakes (order Squamata). They differ from snakes in that they have movable eyelids, external ear openings, and usually legs.

The lizards are strictly land animals, but they live in a variety of land habitats. Some burrow in the ground, many live under rocks and in trees, and some actually glide through the air. Many lizards are well adapted for living in dry desert areas. The American Gila monster stores fat in its tail. It breaks down the fat to provide both food and water. The horned lizard, sometimes incorrectly called a horned toad, has thick platelike scales that prevent water loss. The desert iguana is reported to be able to withstand temperatures as high as 47°C.

MAIN IDEA

Lizards are closely related to snakes. Many are well adapted for desert life. Chameleons can change their color and have unique eyes.



The Gila monster, shown above, is the only poisonous lizard in the United States. It is an endangered species and protected by law in Arizona. The horned lizard, shown at left, feeds largely on insects.

SCIENCE BACKGROUND

Lizards and snakes shed their exoskeletons periodically, but the exact cause and benefit is still unknown. Lizards shed their skin in strips and usually eat it. Snakes shed theirs whole.

The lizard that glides between trees is *Draco*, a lizard of India.

Some lizards have on the top of their head a third "eye," called a pineal eye. Its function is a mystery.



The Old World chameleon ranges from Asia Minor, through North Africa, and into southern Spain. It lives in trees and feeds on insects.

The Gila monster is the only poisonous lizard in the United States. It is seldom dangerous because of its shy habits and the fact that it must chew something before the poison can be injected.

The chameleons are usually considered to be the most amazing lizards. Most live in trees, where they stalk insects. They capture their prey with a sticky tongue that can be shot out more than half the length of their body. They also have chromatophores that allow them to change color to blend with their surroundings. A most amazing feature is their eyes, which can rotate in all directions. Unlike many other reptiles, the chameleons have very sharp vision.

30-4 Snakes The snakes are probably feared by more people than any other animal. The snake, or serpent, has always been associated with the lowest kinds of human behavior. This is unfortunate because most snakes are completely harmless and they have a very important role in nature. Snakes are predators, and many feed on small animals such as mice and ground squirrels, which can destroy crops and grasslands if population growth is unchecked.

Snakes are without legs and ears and have poor vision. But they have other adaptations for locomotion and for sensing their environment. For locomotion they have wide scales on their ventral side. These scales are like tractor treads that hold on to the surface as the body muscles contract and pull the snake forward. Locomotion is a problem only on smooth surfaces or on loose sand. The sidewinder rattlesnake of the southwestern United States solves the latter problem by throwing its whole body sideways.

One of the snake's sensing devices makes use of its forked tongue. Observe a snake closely and you will see that it constantly sticks out its tongue as it moves forward. It is sampling the air, and the tongue is collecting the samples. Molecules and tiny particles of substances in the air are caught on the forked tips of the tongue. Then the tips are inserted in a special organ in the roof of the mouth. This organ, called **Jacobson's organ**, has sensory nerves for taste and smell.

The sidewinder rattlesnake of the southwestern United States feeds on small mammals, such as rodents, and also on lizards. It is chiefly nocturnal.



A snake uses its forked tongue to sample the environment. The pit on the side of this rattlesnake's head is a heat-detector, useful for tracking mammals and birds.

MAIN IDEA

Snakes are predators. They have excellent senses of taste and smell. Pit vipers have infrared detectors to track warm-blooded prey.





The pit vipers are poisonous snakes that are native to Asia and to North and South America.

The pit vipers, which include rattlesnakes, copperheads, and water moccasins, have another unique sensing device. Small cavities, or pits, below the eyes are infrared radiation detectors. All warm bodies give off infrared rays. The pit vipers prey upon warm-blooded animals, such as birds and mammals, which maintain a constant body temperature. The pit vipers can find and track warm-blooded animals in total darkness, or even if they are blind.

MAIN IDEA

Snakes have adaptations such as their jawbone, skeleton, and breathing passages that allow them to swallow large prey whole. Constrictors kill their prey by squeezing.

SCIENCE BACKGROUND

An interesting adaptation of snakes is the way they often hibernate with other species. In one den 250 snakes of three species were found all wound together. In another with 62 snakes, there were seven different species of snakes and 15 amphibians of three species.

30–5 Feeding adaptations Snakes have a number of adaptations that allow them to feed in a special way. They prey on animals or animal eggs, and they swallow their prey whole. Their adaptations allow them to swallow food that is much larger in diameter than their own body.

One of the adaptations is their unique lower jaw. The two bones of the lower jaw are connected by elastic tissue that allows them to separate. Also the skin and other tissues around the mouth and digestive tube can stretch and allow the snake to surround the food. Another adaptation in the head region is the arrangement of the nostrils and air passages for breathing. They are arranged so that swallowing a large animal does not cut off the snake's air supply. A fourth adaptation is the nature of the snake skeleton. Unlike the other reptiles, snakes have ribs that are unattached at one end. Other reptiles have a sternum, or breastbone. The unattached ribs are free to expand. This helps a snake to swallow a large animal.

Most snakes catch their prey with their mouth, then hold it with their body while they swallow it alive. But some snakes, called **constrictors** (kən strik'tərs), catch their prey and squeeze it until it dies. Many of the constrictors are huge, powerful snakes that can kill large animals, such

as deer and antelope. The anaconda is a South American constrictor that sometimes reaches a length of 8 m. The regal python of Malaysia is another constrictor. It reaches 9 m in length.

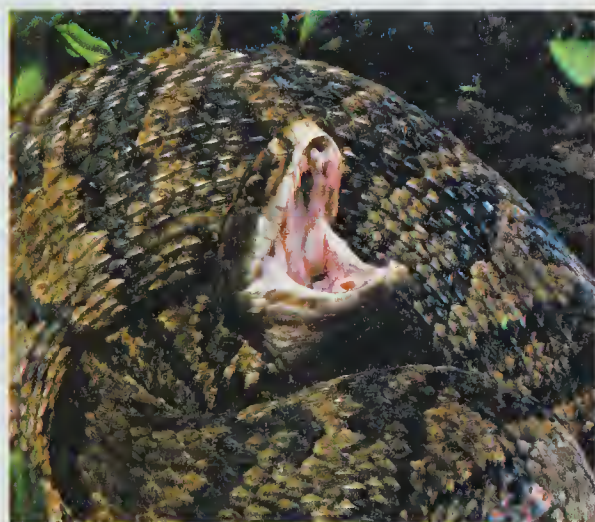
Another group of snakes—the poisonous, or venomous, snakes—kill their prey with a venom.

30–6 Poisonous snakes Snakes use two different kinds of venom, or a combination of both. One type of venom is **hemolytic** (hē mə lit'ik), which means that it breaks down red blood cells and small blood vessels. The pit vipers use a hemolytic venom. The other venom is a **neurotoxin** (nūr ō tok'sin), which means that it acts upon the nervous system and causes paralysis. Snake neurotoxins are the most deadly. They act quickly on the eyes, causing blindness. Examples of snakes that kill with neurotoxins are the coral snake and the cobra.

There are three poisonous snakes in Canada. All of them are rattlesnakes that use hemolytic venom. The Eastern Massasauga rattler is found in the Georgian Bay area of Ontario. The Prairie rattlesnake is common to Saskatchewan and Alberta, while the Northern Pacific rattlesnake is found in British Columbia.

MAIN IDEA

Hemolytic venom acts on the red blood cells and the small blood vessels. Neurotoxins act on the nervous system. Even poisonous snakes have natural enemies.



The only poisonous snakes in Canada are rattlesnakes, e.g. the Massasauga rattler (above left). Poisonous snakes in the United States include the copperhead (left), the coral snake (directly above), and the cottonmouth (top).

Snakes swallow their prey whole. The lower jaw of a snake is loosely attached to the skull, allowing the mouth to open wide enough to swallow animals larger in diameter than the snake.



SCIENCE BACKGROUND

New Zealand is the only major land area that has no native snakes. Madagascar has no poisonous snakes. The largest venomous snake is the king cobra.

SCIENCE TERMS

Jacobson's organ
constrictors
hemolytic
neurotoxin
carapace
plastron

MAIN IDEA

Snakes reproduce by three different methods: by hatching eggs, by live birth, and by eggs combined with nourishment from the mother.

Some snakes have long, hollow fangs, which they inject with a stabbing motion. The pit vipers are in this category. Other snakes have shorter teeth and inject their poison by biting down upon the flesh of an animal. The coral snake injects its poison by this method.

In the United States most poisonous snakebites are inflicted by the copperhead. However, it is the Texas diamondback that causes the most deaths. Altogether about 1 500 people per year suffer poisonous snakebites, and deaths average 45 per year. This contrasts greatly with India, where an average of 25 000 people die every year from snakebites, mostly from cobras.

It is interesting that even poisonous snakes have their enemies. The eastern diamondback rattlesnake, one of our largest poisonous snakes, is killed by the king snake, which is immune to its venom. Many of our poisonous snakes are killed by owls, hawks, and eagles. In India the little mongoose is a deadly enemy of the cobra. And in South America the fer-de-lance, which probably has the deadliest poison of all snakes, is killed by a skunk.

30–7 Reproduction Snakes reproduce by three different methods. Some just lay eggs from which the young hatch. Others, like the rattlesnakes, give birth to living young. By this method the female snake retains the eggs inside her body until they are ready to hatch. The third method is practiced by garter snakes and some lizards. The female snake retains the eggs, which provide part of the nourishment for the developing young. But the developing snakes also obtain nourishment from the body of the female.

30-8 Turtles and tortoises The turtles and tortoises make up the second major group of surviving reptiles (order Chelonia). Both names, *turtle* and *tortoise*, are common names that are not always used precisely. But generally *turtle* is used to describe aquatic species and *tortoise* to describe those that live on land. Both have about the same structure, and we shall use the name *turtle* in describing their characteristics.

One characteristic of turtles is well-known. Their body is surrounded by a bony, sometimes leathery, case. When danger threatens, they can withdraw head, tail, and legs into the case and survive most kinds of predators. The case itself is made up of two parts. The dorsal and largest part is the **carapace**. The ventral and flat part is the **plastron** (plas'trən).

Turtles have jaws but no teeth. They all lay eggs that have firm, calcified shells, like those of birds. Most are herbivorous, and the common box turtle is reported to be fond of wild strawberries. The snapping turtle, common in lakes and ponds of the eastern and midwestern United States and southern Canada, is a ferocious carnivore. It preys on fish, frogs, and even water birds.

30-9 Alligators and crocodiles The alligators and crocodiles of today are practically the same as fossil species that lived 160 million years ago. The species today are just a tiny part of a large group that once lived on the earth (order Crocodilia). They are large animals, with heavy bodies, sharp teeth, and powerful jaws. Most are aggressive predators and some will attack and kill humans.

The American alligator is found from the Carolinas south to Florida and west to Texas. Its closest relative is the Chinese alligator.



The alligator snapping turtle feeds on both plant and animal matter. It lives in slow-moving rivers, ponds, and lakes.

MAIN IDEA

Alligators and crocodiles today are similar to those that were far more common millions of years ago. They are severely limited to certain habitats because they are cold-blooded and aquatic.



ANSWERS TO CHECK YOUR FACTS

1. From about 80 million to 180 million years ago. Compared with amphibians, reptiles might still be considered successful. However, compared with mammals or insects, or compared with their previous position, reptiles cannot be considered a success.
2. It is thick and is composed of dry scales, sometimes with bony plates underneath. No, they also have an endoskeleton.
3. They breathe with lungs.
4. The egg. It eliminates the need to return to the water to reproduce.
5. They have movable eyelids, external ear openings, and usually legs.
6. The Gila monster stores food and water in the fat of its tail. The horned lizard has scales that prevent water loss.

ANSWERS TO REVIEW QUESTIONS

1. They have a very long tongue, the ability to change color, keen vision, and eyes that can rotate in all directions.
2. Their forked tongue takes samples from the air and inserts them in the Jacobson's organ in the roof of their mouth. This organ has sensory nerves for taste and smell.
3. They detect infrared radiation. They are used to track warm-blooded prey.
4. Snakes that squeeze their prey till it dies. Large constrictors can kill such animals as deer and antelope.
5. Their jawbone is hinged by elastic tissue; the skin and the tissues surrounding the mouth and the digestive tube can stretch; the breathing passages are arranged so that swallowing a large animal will not cut off the supply of oxygen; and the ribs are unattached at one

There are two species of this group that live in the United States. By far the most common is the American alligator, which has a short, broad snout. The American alligator is most plentiful in Florida and Louisiana, but once it thrived in several states.

The other species is the American crocodile. It has a longer and narrower snout than the alligator. It is common on the coasts of Central America and in other areas of the Caribbean Sea. In the United States the crocodile is found only along the southern coast of Florida.

Alligators are usually not as aggressive as crocodiles. However, they are the only reptiles known to produce vocal sounds. Both male and female alligators make loud belching calls, usually during breeding season.

Being aquatic reptiles, alligators and crocodiles are severely limited in the habitats where they can survive. Like all reptiles, they are cold-blooded. If they venture in water that is below 21°C, their muscles will stop working, and they will settle in the water and drown.

30–10 The tuatara The sole survivor of another major group of reptiles is called the tuatara (order Rhynchocephalia). It looks somewhat like an iguana lizard, but its anatomy is very different. The only survivors live on the Cook Islands, which are between the two main islands of New Zealand. The tuatara adult is about 60 cm long, and one is reported to have lived for 77 years. The government of New Zealand carefully protects the few surviving tuataras.

Although it looks somewhat like a lizard, the tuatara belongs to a different order of reptiles, all other members of which are extinct.



CHECK YOUR FACTS

1. When were the reptiles the dominant animals on earth? Are they still successful?
2. Describe the exoskeleton of reptiles. Is this their only skeleton?
3. How is gas exchanged in reptiles?
4. What is the main adaptation that has enabled reptiles to succeed on land? Why?
5. How do lizards differ from snakes?
6. Describe some adaptations in lizards that enable them to live in desert environments.

SUMMARY

Before their decline about 80 million years ago, the reptiles were the dominant animals on earth for 100 million years. Comparatively few reptiles remain today. Several advancements over the amphibians make reptiles much better suited to life on land. A thick exoskeleton effectively prevents water loss. The egg is covered with a shell that resists drying.

REVIEW QUESTIONS

1. What uncommon characteristics are seen in the chameleon?
2. How do snakes taste and smell?
3. What are the pits for in pit vipers? How are they used?
4. What are constrictors? Can they kill large animals?
5. How are snakes adapted to swallow their prey whole?
6. What are the three poisonous snakes found in Canada?
7. What are the effects of the two types of snake venom? Give two examples of snakes that use each type.
8. Snakes reproduce by three different methods. Explain.
9. How do snakes move? What different mechanism does the sidewinder use?
10. What do the carapace and plastron compose? Of what use is this structure?

ANALYSIS AND APPLICATION

1. Compare the hearts of frogs, snakes, and crocodiles. Which is more advanced?
2. Why are snakes mostly beneficial to humans?
3. Why are alligators and crocodiles able to survive in only a few habitats?

end, allowing them to expand.

6. The Eastern Massasauga rattler, the Prairie rattler, and the Northern Pacific rattler.

7. Hemolytic venom breaks down red blood cells and small blood vessels. Neurotoxins cause paralysis, acting quickly on the eyes and diaphragm. Rattlesnakes and copperheads use a hemolytic venom. Cobras and coral snakes have neurotoxins.

8. Some lay eggs from which the young hatch. Others give birth to living young. Still others retain the eggs in the body of the female, and nourishment is obtained from both the egg and the mother.

9. Most snakes move by contracting the body while scales on their ventral surface anchor them to the ground. The sidewinder throws its whole body sideways.

10. They compose the case of turtles and tortoises. It is used to protect the body of the animal it encases.

ANSWERS TO ANALYSIS AND APPLICATION

1. The frog heart has one ventricle. The snake heart has a partial wall in the ventricle that helps prevent the mixing of blood from the lungs with that from the body. The crocodile heart has a complete wall in the ventricle, making it a four-chambered heart. The crocodile has the more advanced heart of the three.

2. Many snakes prey on small rodents that would cause problems if their population growth were unchecked.

3. They are both aquatic and cold-blooded. Unlike terrestrial reptiles, aquatic reptiles face death should their habitat drop in temperature. Thus they are confined to warm, aquatic habitats.

Investigation 49 from *Laboratory Investigations in Biology* can be done with this chapter.

31 *The Birds*



OBJECTIVES

- To list the basic structural characteristics of birds
- To understand the structure of the various kinds of feathers and how each kind functions in flight, in mating, or as insulation
- To discuss the unique structure of the bird's skeleton and how it is adapted for flight
- To understand the different structures of bird wings
- To appreciate that bird migration is still a riddle

31-1 *The most admired animals* In the last chapter we discussed the reptiles, which are probably the least admired of all the animals. Now we shall discuss the animals that are in the opposite category. The birds (class Aves) are probably the most admired of all the different animals. Some people admire them for their color and beauty. Others admire them for their songs and their behavior. In past ages, before humans learned to fly airplanes, they were admired with envy because of their ability to fly. No other animal possesses so many beautiful adaptations for a single purpose, that of flight. The head, the wings, the feathers, and most of the internal systems are unique within the animal kingdom. The systems are as effectively adapted for flying as are the systems in airplanes.

31-2 *General characteristics* Even a small child can tell the difference between a bird and any other animal. One reason is that the bird is always covered with feathers. Feathers are not found on any other animal.

Another characteristic the birds share only with insects and certain mammals such as bats is the possession of wings. The wings, of course, are normally used for flying. However, there are exceptions. The penguin has wings that are used for swimming. The ostrich has small wings that have no function.

All birds have a lightweight, but strong, horny beak. The beak may be adapted for a variety of feeding activities, such as cracking seeds, stabbing insects or fish, and scooping food out of water. No birds have teeth, which is a weight-saving adaptation.

MAIN IDEA

Zoologists regard birds with admiration because of the beautiful adaptations that allow them to fly.

SCIENCE BACKGROUND

The birds outnumber all other vertebrates except fishes. Bird fossils are rare, probably because their bones are so lightweight and easily decomposed.

MAIN IDEA

Birds are characterized by feathers, wings, a beak, and a hard-shelled egg laid outside the female's body. They are warm-blooded and have a four-chambered heart.

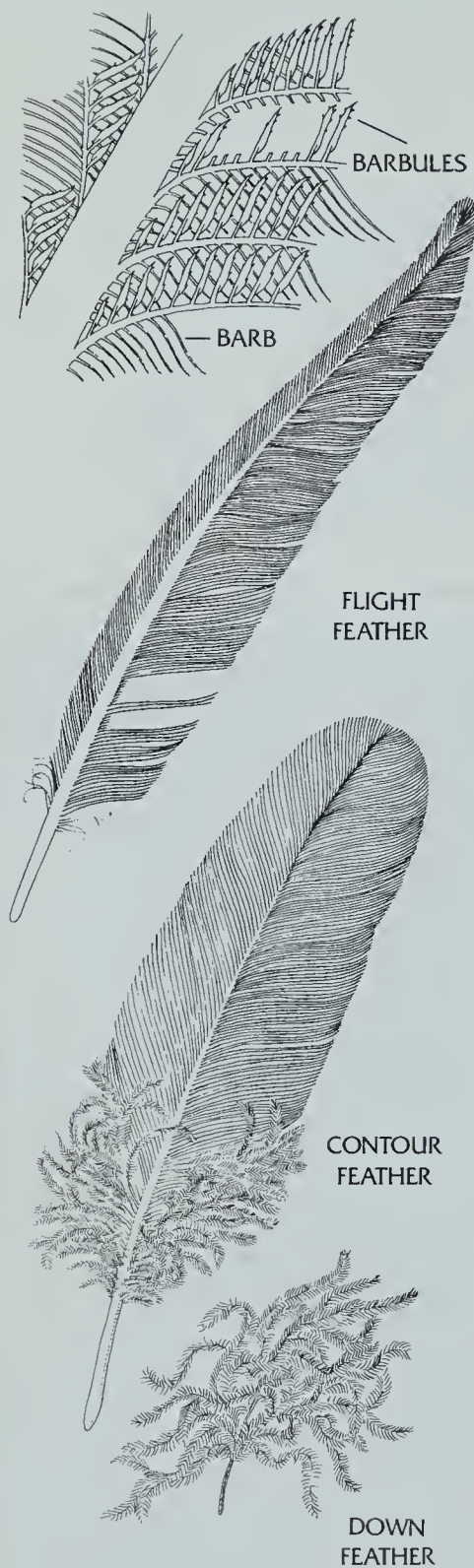


FIGURE 31-1

The distinguishing characteristic of birds is feathers. The three types of feathers found on birds are illustrated in this figure.

Birds reproduce only from eggs that are laid outside the female's body. Bird eggs are always enclosed in a hard shell. Each egg has a large yolk that provides food for the developing bird.

The birds possess major advances over the reptiles in terms of internal body functions. All birds have a four-chambered heart. In the four-chambered heart there is a complete separation between blood in the pulmonary circulation and blood in the systemic circulation. All birds are warm-blooded animals. This means that they can maintain a warm and fairly constant body temperature in any environment. This gives them a great competitive advantage over most other animals. They can be active during all seasons of the year, and in all habitats on the earth.

31-3 Feathers The birds are considered by zoologists to be very closely related to reptiles. Feathers are believed to be highly adapted reptile scales. Reptilelike scales still exist on the feet of birds.

Feathers have several unique characteristics. They are extremely light in weight, yet very strong. (Lift a feather and see how light it is, then try to pull it apart.) Each feather has a central **shaft** (shäft), which ends in a hollow **quill** (kwil). The quill is buried in the skin. On each side of the shaft there are hairlike **barbs** (bärbs) that lie parallel with each other. They are linked together by branches called **barbules** (bär'byüls), which usually have little hooks on them. The hooks link the barbs so that they remain fixed in one position, and the feather maintains its flattened shape. At times, however, the hooks may become unfastened. The bird "zips" them back together with its bill, a process called **preening** (prēn'ing). We can do the same with our fingers. During preening the bird strokes a gland near its tail and obtains a substance that it applies to the feathers. The substance is thought to help waterproof the feathers and keep them from getting brittle.

There are three basic kinds of feathers on birds. The **flight feather** is found on the wings and tail. It is longer than the other feathers and its shaft is very strong. The second type of feather is the **contour** (kon'tür) **feather**, which covers most of the body. The contour feather is shorter and broader than the flight feather. It has a patch of down near the bottom of the shaft. The third type of feather is the **down feather**. The down feather is short and has no shaft. Its function is to trap air and provide insulation so that the bird will not lose its body heat. Some birds have many more down feathers than others. Ducks and geese have them by the thousands.

The feathers function during flight and they help to insulate and protect the body. They also function during mating. For some birds the color and pattern of feathers is used for recognizing mates. Other birds make special displays out of their feathers, such as the fanlike tail display of the peacock.

Feathers are shed from time to time by a process called **molting** (mōlt'ing). Most birds molt their feathers a few at a time, so their flying ability is not affected. Certain others, such as ducks and geese, molt all at once and for a short time lose their ability to fly.

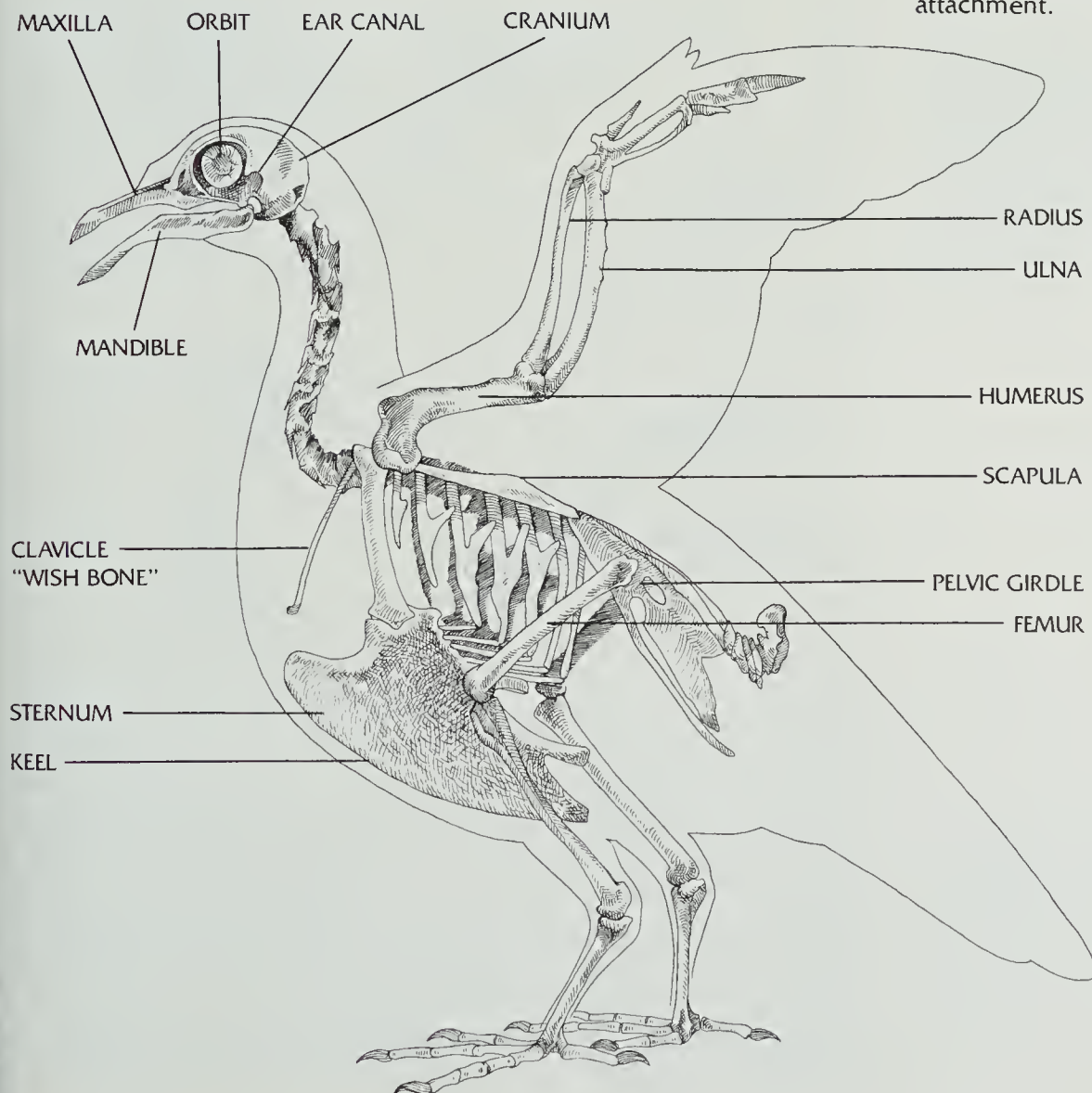
31-4 The skeleton Engineers who design airplanes have one thought uppermost in their mind: *avoid excess weight!* There is no better model for them to study than the bird skeleton. It is amazingly light. Often it is even lighter than the bird's feathers.

MAIN IDEA

The skeleton is well adapted for flight because it is lightweight, it provides for the attachment of large muscles, and it gives the body strength and rigidity as the wings move up and down.

FIGURE 31-2

The skeleton of a bird has several adaptations for flight. The bones are mostly hollow. The sternum is enlarged for flight muscle attachment.



SCIENCE BACKGROUND

The skeleton of a frigate bird with a 2.5 m wingspread weighs only about 114 g, which is less than the weight of its feathers.

Some students might appreciate a discussion of center-of-gravity and flying machines, emphasizing that the weight must be concentrated directly beneath the wings.

Though relatively immobile, the bird eye is usually much keener than the human eye. Hawks and eagles probably have an acuity eight times that of the human eye.

MAIN IDEA

High-energy demands are met by eating more food, eating high-energy foods, and digesting food more quickly. Birds have a crop that stores food and a gizzard that chews food.

MAIN IDEA

The circulatory system of birds is similar to that of humans, except that the heart rate and the body temperature are higher.

The bird skeleton is lightweight because the bones are mostly hollow and filled with air. Also there is an absolute minimum of bony tissue. For example, the skull is very small and thin, and the lack of teeth makes it unnecessary for the bird to have jawbones.

The skeleton has other adaptations as well. Most of the main body vertebrae are fused together to form a rigid backbone. This gives the main part of the body strength and rigidity as the wings move up and down. Another adaptation is the **keel** (kēl), which is the large specialized breastbone. The keel provides a place where the large, powerful flight muscles can attach. Also the neck vertebrae have a unique adaptation. They can easily slide over each other when the neck is turned. This allows birds, which cannot move their eyes, to turn their necks more than other animals. Some, like the owl, can turn their head completely around.

31–5 Food and digestion Flying demands much more energy than running or walking. The birds have solved this problem in several ways. Generally they consume more food per body weight than most other animals. Also the foods they eat are often high-energy foods that can be digested rapidly. An extreme example is the hummingbird. It uses up tremendous amounts of energy with its rapid flight, but it feeds on flower nectar, which is quick to digest and loaded with energy.

The digestive system of birds also works more rapidly than that of most other animals. A bird such as the thrush can pass berries completely through its digestive system in 30 min. A shrike can digest a mouse in 3 h.

Two unique adaptations in some birds are the crop and gizzard. In some birds the crop is thin-walled and capable of stretching to hold a tremendous amount of food. The gizzard is a thick, muscular organ that grinds food and duplicates the function of teeth. Some birds eat small stones that remain in the gizzard and help crush food such as hard seeds.

31–6 Circulation Birds have a four-chambered heart and a circulatory system similar to our own. However, the heart rate—which is the average number of contractions, or beats, per minute—is much faster. Our own heart rate is about 72 beats per minute. The heart rate of a chicken is 250 beats per minute, while the heart rate of a canary is about 1 000 beats per minute.

Birds also have the highest temperatures of all animals. Our body temperature averages 37°C. The average body



FIGURE 31-3

The beaks of different species of birds are specialized according to the feeding habits of the particular species.

SCIENCE BACKGROUND

Birds have a narrow tongue that is sometimes adapted for special purposes. The woodpecker has a barbed tongue, which it uses to spear insects. Hummingbirds have a sticky tongue for obtaining nectar.

Pigeons have a special adaptation of their crop. It produces "bird milk," which is used to feed the young. Bird milk is also produced by emperor penguins, flamingos, and some shearwaters.

Bird wastes are whitish in color because of the uric acid that is secreted by the kidneys and combined with intestinal wastes. Birds do not have a urinary bladder nor do they produce urine like other vertebrates.

temperature of birds is 40°C – 42°C . However, body temperatures of birds are not as uniform as those of humans and many mammals. For example, the temperature of a sparrow can range between 23°C and 44°C .

31-7 Gas exchange Along with a great demand for energy comes a greater need for oxygen. The birds have solved that problem with a system for gas exchange that is very different from that of reptiles or mammals.

Birds have small lungs that have only a limited ability to expand. However, their lungs are connected with nine air

MAIN IDEA

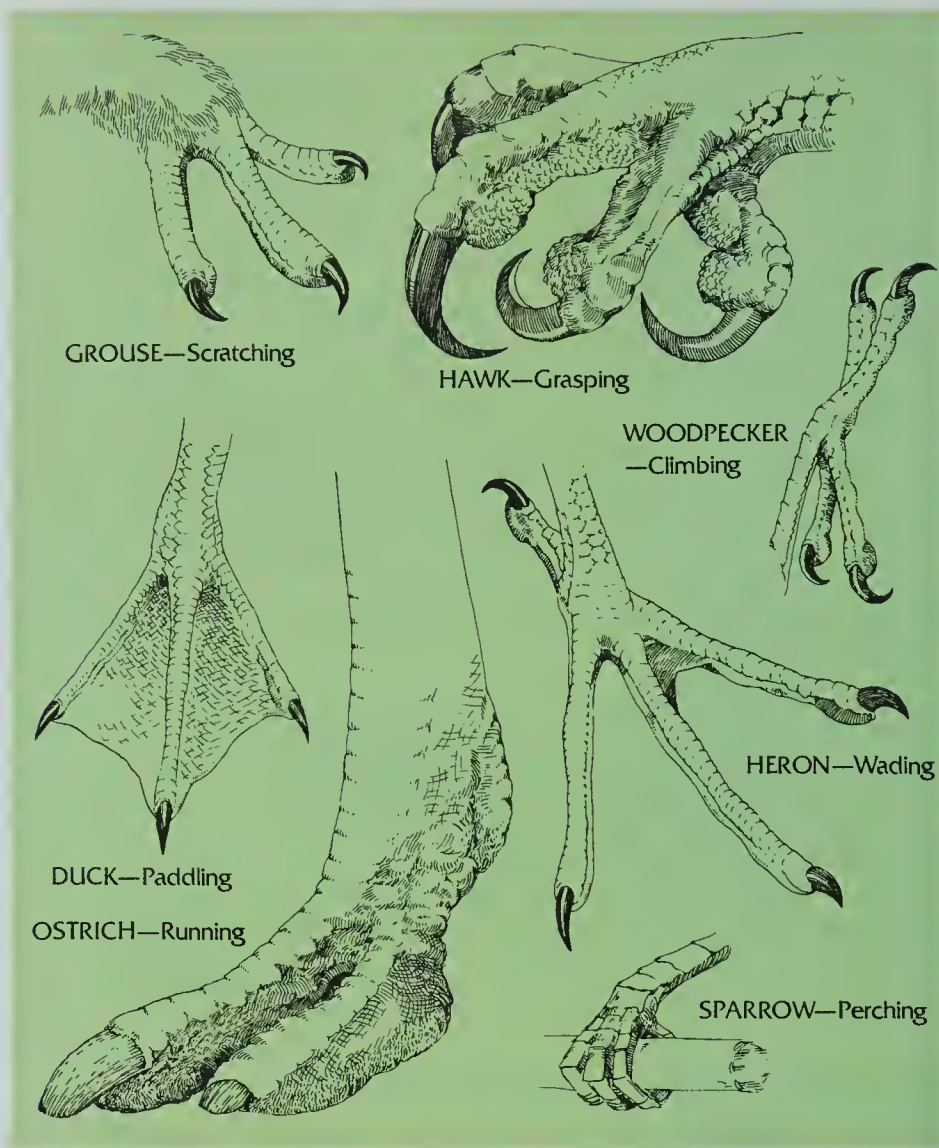
Bird lungs obtain oxygen during both stages of breathing because they have air sacs attached to their lungs.

FIGURE 31-4

The feet of different species of birds are adapted to the habitat and life-style of the particular species.

SCIENCE BACKGROUND

The bird lung does not have alveoli as other vertebrate lungs do. Instead, it has cavities called air capillaries where the gas exchange occurs. About 75 percent of the inhaled air goes into sacs and reservoirs. The unique breathing system also helps cool the bird, because the air absorbs heat throughout the interior of the bird body.



sacs that are scattered throughout their thorax and abdomen, and also into some of the hollow spaces of the bones. When the bird breathes in, or **inhales**, (in hālz'), the air goes through lungs and into the air sacs. When it breathes out, or **exhales** (eks hālz'), the air moves from the air sacs back through the lungs and out the body. By this method the lungs obtain oxygen when the bird inhales and when it exhales. All other animals obtain oxygen only when they inhale.

MAIN IDEA

Wings are shaped to achieve a particular function, such as maneuvering, high speed, or soaring.

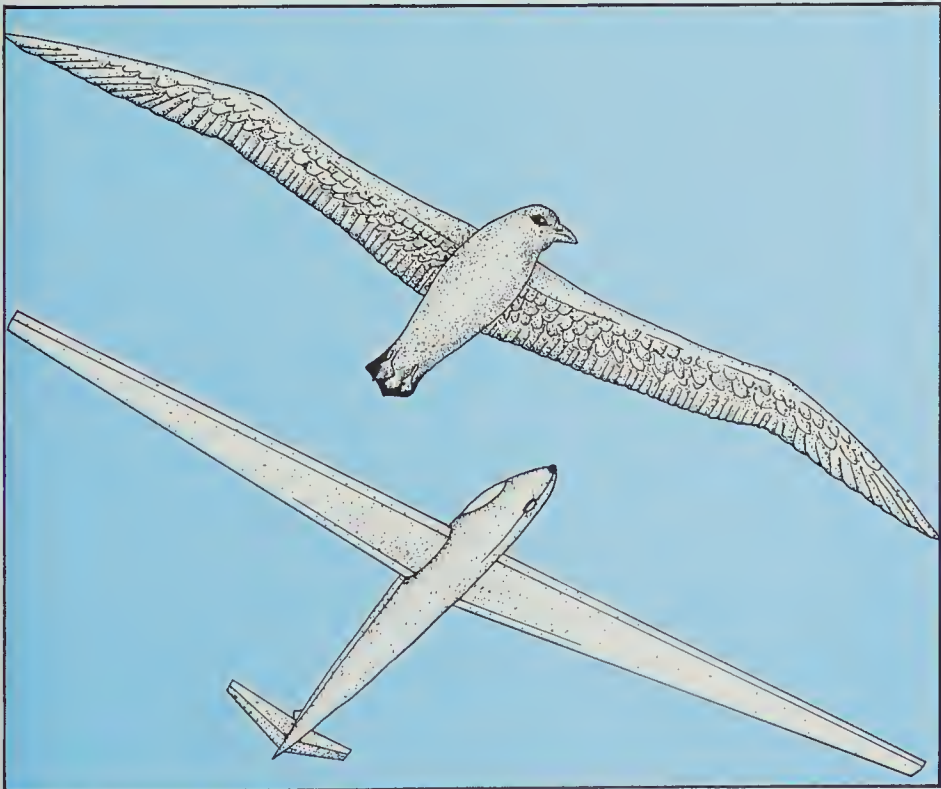
31-8 Bird flight Earlier we mentioned that an aircraft engineer could study the bird skeleton as a model for a strong but lightweight structure. The same recommendation applies to the shape and overall design of different types of bird wings. The bird wings are adapted for different kinds of flying, and in some cases aircraft wings have been developed with the same design. An example is the

maneuvering (mə nü'var ing) **wing**, which is found usually on tree-dwelling birds that must turn sharply and maneuver among tree branches. The maneuvering wing is elliptical in shape, that is, curved on both the front and back edges. Compare such bird wings with the wings of one of the most maneuverable World War II fighter planes, the British Spitfire.

Another type of wing is the **high-speed wing**, which is found on swallows, hummingbirds, swifts, terns, and falcons. This wing is swept-back and tapers all the way to the tip. Jet airplanes have swept-back wings.

A third type of wing is the **soaring** (sôr'ing) **wing**. On ocean birds such as the albatross and gull, the soaring wing is long and narrow. On land-soaring birds, such as the condor and some hawks, the wing is wider and often square at the tip. The land-soaring birds have more maneuverability with the wider wing, but the ocean birds can soar for hours without moving their wings. The overall advantage of the soaring wing is that these birds can use wind and rising air currents to keep aloft. Thus they do not have to burn up large amounts of energy as they look for food. Airplane gliders, with the same kind of wing as the ocean-soaring birds, can also soar for hours. They use no energy once they are airborne.

FIGURE 31-5 Notice the similarity between the soaring wings of an albatross and the wings of a glider plane.



SCIENCE BACKGROUND

Another type of bird wing is the high-lift wing of predator birds such as owls that have to carry a heavy load.

SCIENCE BACKGROUND

One reason why northern latitudes are better for raising young is that there are fewer predators. With great seasonal variations in their food supply, there are few predator populations and smaller numbers in the populations. Another advantage is the abundant but relatively uncontested food supply that is available during the northern summers.

SCIENCE TERMS

- shaft
- quill
- barbs
- barbules
- preening
- flight feather
- contour feather
- down feather
- molting
- keel
- maneuvering wing
- high-speed wing
- soaring wing
- precocial
- altricial
- bird parasite



The arctic tern, which feeds on small fishes and crustaceans, migrates from the arctic area to Antarctica and back every year.

ANSWERS TO CHECK YOUR FACTS

1. Because they are so effectively adapted for flight.
2. The ability to maintain a fairly constant body temperature. Warm-blooded animals can be active during all seasons.
3. They have feathers, beaks, wings, a hard-shelled egg laid outside the female's body.
4. The central shaft ends in a quill buried in the skin. Parallel barbs on the shaft are linked by barbules. Hooks link the barbules.
5. The feathers are flattened and waterproofed.

ANSWERS TO REVIEW QUESTIONS

1. The process of shedding feathers. Some birds molt all at once, but most do not.

31-9 Migration Animals do some amazing things, but bird migration is one of the most spectacular. The typical pattern is for a bird to spend the summer months at the northern latitudes, then fly south to a warmer climate for the winter. This behavior solves two main problems for birds. First, it puts them in a habitat where food is always available. Second, it allows them to reproduce and raise their young under the most ideal conditions.

What is most amazing about bird migration is the ability of birds to fly and navigate accurately over long distances. The record setter in this category is the arctic tern. It spends the summer at the Arctic Circle, then migrates 17 700 km to Antarctica.

Zoologists have performed a number of experiments to determine how birds navigate. These experiments have shown that birds use landmarks and stars in the night sky to guide them. But there are still mysteries about the process.

31-10 Reproduction The bird's nest is a well-known adaptation. The nest is usually a home for the eggs before hatching and for the young, dependent birds. However, there are two distinct patterns of bird development. The type of nest usually depends on the kind of bird being reproduced. Some birds, called **precocial** (pri kō'shəl) birds, are well developed when they are born. They are covered with downy feathers, and within an hour or so after birth, most of them are capable of being on their own. Most of the birds in this category nest on the ground. Examples are the chicken, duck, quail, and grouse. The parents of such birds are relieved of much of the burden of feeding their young. The young have some ability to protect themselves against predators.

The second type of bird is the **altricial** (al trish'əl) bird. Most birds belong to this group. The altricial bird lays smaller eggs than does the precocial bird. And the developing altricial bird spends less time in the egg. The young of altricial birds are born naked, blind, and completely helpless. But they do have an instinctive ability to open their mouths and feed. Usually the parents are continuously hunting for food. The **bird parasite** (par'ə sīt) is also an altricial bird. About 80 species of these birds lay their eggs in the nests of other birds. The eggs are then hatched by the foster parents. Often the newborn imposters root out the young, rightful residents of the nest. In Europe and in Africa, the cuckoo is one of the best-known bird parasites. In America it is the cowbird that has the worst reputation for parasitizing the nests of the songbirds.

CHECK YOUR FACTS

1. Why are the birds studied with such admiration by zoologists?
2. What do we mean by warm-blooded? Why is this an advantage?
3. What are some distinguishing characteristics of birds?
4. Describe the structure of a feather.
5. What two benefits result from preening?

SUMMARY

The birds are greatly admired for their beauty, their singing, and their ability to fly. The entire body—feathers, wings, head, internal organs—is effectively adapted for flight. Feathers, wings, and a horny beak are characteristics of birds. Birds reproduce from hard-shelled eggs laid outside the female's body. They are warm-blooded and are thus active in all seasons all over the world.

REVIEW QUESTIONS

1. What is molting? Does it occur all at once?
2. How is weight reduced in the bird skeleton?
3. How is the bird skeleton adapted for flight?
4. How do birds satisfy the energy requirements of flight?
5. What unique structures are found in the digestive system of birds? How do they benefit the animals?
6. Compare the heart rate and body temperature of humans with that of birds.
7. How do birds meet their large demand for oxygen?
8. Describe the shape of three types of wings.
9. Why is migration beneficial?
10. Name and describe the two patterns of development found in birds.

ANALYSIS AND APPLICATION

Can you match the terms with the birds?

- | | |
|-----------|------------------------------|
| a. gaggle | 1. quail |
| b. skein | 2. doves or swallows |
| c. herd | 3. sparrows |
| d. bevy | 4. chickens |
| e. covey | 5. quail |
| f. brood | 6. partridges |
| g. flight | 7. geese (flying) |
| h. host | 8. geese |
| | 9. swans, cranes, or curlews |

2. The bones are mostly hollow, there is a minimum of bony tissue, and no teeth or jawbones.

3. The main body vertebrae are fused to form a rigid backbone that can support the body during flight. A specialized breastbone, the keel, provides a place for flight muscles to attach.

4. They can digest food more quickly than most animals. They consume more food per body weight. They eat high-energy foods that are easily digested.

5. The crop—stores food, enabling the bird to go longer without feeding, and the gizzard—chews food, allowing the bird to function without teeth.

6. The heart rate of birds is faster. The body temperature of birds is generally warmer, but it is much more variable.

7. Their lungs are connected to nine air sacs. Air passes through the lungs during inhalation and exhalation.

8. Maneuvering wings are elliptical. High-speed wings are swept back and tapered. Soaring wings are long, narrow, and sometimes square at the tip.

9. It puts the bird in an ideal environment for raising young.

10. Precocial birds are well developed when they are born. They usually nest on the ground. Altricial birds produce smaller eggs and the young are born naked, blind, and helpless.

ANSWERS TO ANALYSIS AND APPLICATION

Gaggle—geese; skein—geese (flying); herd—swans, cranes, or curlews; bevy—quail; covey—partridges or quail; brood—chickens; flight—doves or swallows; host—sparrows.

Investigation 50 from *Laboratory Investigations in Biology* can be done with this chapter.

32

The Mammals



OBJECTIVES

- To explain that the mammals replaced the reptiles as the dominant animals on earth
- To name the unique characteristics of mammals
- To list the three main groups of animals
- To understand the unique characteristics of the major orders of mammals
- To understand the unique characteristics of the primates

The Dominant Animals

32-1 From reptiles to mammals For nearly 100 million years, the reptiles were the dominant animals on the earth. As the reptiles began their decline, a new group—the mammals—took over. They soon replaced the reptiles as the dominant animals. Today the mammals dominate the major habitats on the earth.

Why have the mammals been so successful? There are several reasons for their success. One of the main reasons is their level of intelligence. The mammals are the most intelligent of all the animals. Another reason for their success is their adaptability. Mammals can change their behavior to adapt to new conditions. A third advantage, which the mammals share with the birds, is their ability to maintain a constant body temperature. Unlike the cold-blooded reptiles, the mammals were able to remain active and survive during the winter season in cold climates.

32-2 Characteristics of mammals Mammals (class Mammalia) have several characteristics that make them different from all other animals. Perhaps the most basic of these characteristics is related to their name. *Mamma* (mam'ə) in Latin means "breast." This name is descriptive of most mammals. The young of mammals are nursed on milk. There is only one small group of mammals that do not have breasts or nipples that the young can suckle. We will discuss this group later.

A second characteristic of mammals is the presence of hair. The amount and placement of hair on their body var-

MAIN IDEA

The mammals have replaced the reptiles as the dominant animals on earth because of their intelligence, their adaptability, and their ability to maintain a constant body temperature.

MAIN IDEA

Mammals nurse their young, have hair, have seven vertebrae in their neck, have fewer skull bones than birds or reptiles, and have the most highly developed brain of all the animals. Unlike other animals, mammals usually care for their young until they reach adulthood.

SCIENCE BACKGROUND

Mammals are found in all possible habitats on earth—in oceans, in streams, underground, in trees, and in the air. There are 4 500 species, about half the 8 600 species of birds.

Zoologists usually avoid debating whether the mammals should be called the most successful of all the animals. The insects are also highly successful, considering their number of species, variety of niches, and general resistance to human activities.



The duckbill platypus belongs to the primitive group of egg-laying mammals called monotremes.

SCIENCE BACKGROUND

Other general characteristics include movable eyelids and a muscular diaphragm separating the thorax and abdomen.

MAIN IDEA

There are three main groups of mammals: the monotremes, or egg-layers; the marsupials; and the placental mammals.

ies from one type of mammal to another. On a lion or a dog, hair covers most of the body. However, on an elephant the hair is sparse. On whales the hair is confined to a few whiskers around the mouth. Mammals shed their hair either seasonally or a little at a time.

Other mammalian characteristics are not so easily observed. For example, mammals have fewer skull bones than the reptiles and birds have. With very few exceptions, mammals have seven vertebrae in their neck, even giraffes with their long neck. Mammals also have the largest and most highly developed brain. They are the most intelligent of all animals.

There is one behavioral characteristic of mammals that is unique in the animal kingdom. Usually the parents take care of their young until they reach adulthood.

32-3 Kinds of mammals There are three main groups of mammals. One group is called the **monotremes** (mon'ə trēms) (order Monotremata). It is the most primitive group and is made up of egg-laying mammals. The duckbill platypus of Australia is the best-known representative of the group. These animals lay eggs that are quite similar to bird and reptile eggs. They do not have breasts, or mammary glands, for nursing their young. Their milk is secreted on their hair. The young lap this milk with their tongues.

The second group of mammals is the **marsupials** (mär sü'pē əls) (order Marsupialia). All marsupials give birth to living young. However, the newborn are very small and poorly developed. An example is the opossum, an American marsupial. This animal is larger than a full-grown house cat. But it gives birth to offspring about the size of a honeybee. After they are born, most marsupials crawl through the mother's hair to a pouch called the **marsupium** (mär sü'pē əm). Hence the name *marsupial* for the group. The young live inside the marsupium for several more weeks. Inside the pouch each one clings to a nipple while completing its development. A few marsupials do not have a pouch. But these young also cling to their mother's nipples while developing.

The third major group of mammals is the largest and includes 16 orders of animals. They are called the placental mammals. These mammals remain inside the female for a

SCIENCE BACKGROUND

The platypus lays 2 or 3 eggs, which hatch in about 10 days. They feed their young for 18 weeks. The male is one of the rare poisonous mammals. It has a spur on its heels with poison glands. The poison will kill small animals and will cause great pain in humans. Another monotreme is the spiny anteater, which has a long tongue that acts like flypaper as it roots in ant and termite nests.

The marsupials in Australia and Tasmania represent the classic example of the zoologist's "convergent evolution" where the marsupials have theoretically evolved into animals similar to rats, cats, squirrels, rabbits, ferrets, anteaters, moles, and wolves. Unfortunately the marsupials are not well adapted for surviving competition with introduced species and with the activities of humans. Without protection many would be near extinction or extinct.



In marsupials, such as this wallaby, the young are born in a very immature state. They continue their development inside a pouch while being nourished with milk.

MAIN IDEA

The insectivores are carnivorous and feed mostly on insects.

SCIENCE BACKGROUND

The insectivores are primitive mammals, which zoologists believe to be the forerunners of many other orders including the primates.

SCIENCE BACKGROUND

The bats are the second largest order of mammals, after rodents. Some zoologists think the pipistrelle from equatorial Africa may be the world's smallest mammal. The flying foxes are the giant bats. Colonies of flying foxes with up to 100 000 members can be found in Australia, hanging from the branches of trees and looking like large fruit. They are fruit-eating bats, and when they range out in search of food in the evening, they resemble flights of geese.

Insects form a large part of the diet of this pygmy shrew and almost all other shrews. Consequently these animals are valuable insect-destroyers.

much longer period of development than do the marsupials. They receive their nourishment through the **placenta** (plə sen'tə). This organ contains numerous blood vessels of both the mother and the developing mammal.

32-4 The insectivores One order of placental mammals is the *insectivores* (in sek tiv'ərz). The insectivores (order Insectivora) include such animals as the shrews, hedgehogs, and moles. These animals are **carnivorous** (kär niv'ər əs), or meat eaters, and feed mostly on insects.

The shrew is a small animal. In fact, a shrew recently discovered in Gabon is the world's smallest mammal. Like all insectivores, the shrew has needle-sharp teeth, which it uses in savage attacks. Shrews are probably the most active of all mammals. They are reported to alternate three hours of feeding with three hours of rest through the day and night. In temperate climates they are active throughout the winter. They are constantly seeking food to satisfy their appetite. In proportion to their size, shrews are thought to be the strongest of all mammals.

The hedgehog is found in Europe, Africa, and Asia. It is a spiny insectivore that feeds on a wide variety of small animals.

The moles include several North American species, all of which live underground. They burrow through the ground at amazing speeds. They feed mostly on insects and earthworms.



32-5 The fliers Perhaps the most unique group of mammals is the group that flies—the bats. The name of the order to which they belong (order Chiroptera) means “hand wing.” This name is appropriate because the bat wing is actually a membrane that is supported by long, fingerlike bones.

Bats are generally divided into three groups, based on their feeding habits. One group is the **fruit-sucking bats**. Actually, some members of this group will feed on fruits, while others feed on the nectar of flowers. The fruit suckers are found in tropical and semitropical regions. A second group of bats—the **insectivorous** (in sek tiv’ər əs) **bats**—are common in the Americas. They have sharp teeth, much like those of the shrew. They catch insects while flying. The third group of bats consists of the **vampire** (vam’pīr) **bats**. They use their razorlike front teeth to puncture the skin of other mammals. When the blood starts to flow, the bat laps it up with its tongue. Its saliva prevents the blood from clotting. Therefore the blood flows until the bat has finished its meal.

32-6 The rodents One group of mammals ranks second after the insects as a troublesome human pest. These are the **rodents** (order Rodentia). Their name describes the way in which they eat. *Rodent* means “gnawing animal,” and all rodents are well equipped for this function.

The rodents make up from one-third to one-half of all the land mammals. They are abundant in most terrestrial ecosystems. The rodents include rats, mice, porcupines, beavers, muskrats, squirrels, prairie dogs, chipmunks, gophers, and hamsters.

Rats and mice make up one of the biggest groups of human pests. They carry and transmit diseases. Both mice and rats destroy tonnes of agricultural products every year. The natural enemies of rodents include eagles, hawks, owls, and many kinds of snakes. Rodents often experience a population explosion and cause much damage in those areas in which they have no predators.

32-7 The runners Another order of mammals, the runners, includes hares, rabbits, and pikas (order Lagomorpha). These are some of the fastest animals. The brown hare, a native of Europe, runs at an estimated speed of 64 km/h. Even racing greyhounds can catch the hare only when it becomes tired.

Three members of this order are well-known in North America. The American cottontail is the smallest one. It is



The little brown bat feeds exclusively on insects that it tracks by emitting high-pitched sounds and detecting the echo.

MAIN IDEA (32-5)

Bats are classified by their feeding habits: fruit-sucking, insectivorous, and vampire (blood-sucking).



The beaver is a member of order Rodentia. Beavers dam streams and small rivers to create ponds and then build lodges in the ponds.

MAIN IDEA

The runners include some of the fastest animals, such as the hares and rabbits.



The jackrabbit is a plains animal and feeds entirely on plant matter. It does not dig burrows, although it may enter them to escape predators.

SCIENCE BACKGROUND

One of the main differences between hares and rabbits is that rabbits are born naked and blind, while hares are born completely furred, with their eyes open, and ready to move about.

common on most of the Continent. Hunters like the cottontail for its quick, darting movements and its tasty meat. The jackrabbit is best known on the western plains. It is larger than the cottontail. It is easily recognized by its long ears and long, loping gait. The snowshoe rabbit, or the varying hare, lives in the northwestern forests and mountains. It molts three times a year, producing coats of gray, gray-brown, and white. It has a white coat in the winter and the darker coats in other seasons. It has large feet with tufts of hair. This is an adaptation that enables it to move in the snow. An interesting fact about the American species is that they are not true rabbits. They are hares. The true rabbits are smaller than the hares. They live in groups and dig burrows in the ground.

The pika looks like a small rabbit with short ears. It lives high in the Rocky Mountains and at high elevations in other parts of the world. Its favorite home is in rock slides. There it can be observed in the summer months hurrying about, gathering grass and stacking it to dry in the sun. Later the dried grass is stored under the rocks and used for food in winter.

32-8 The carnivores A large and important group of mammals (order Carnivora) is made up primarily of meat eaters. These are the carnivores (kār'nə vōrz). Although they are not the only mammals that eat meat, they are the best adapted for that purpose. They have four fang-like teeth that are used for ripping and tearing meat. Behind the fangs are other sharp teeth that are also adapted for cutting skin, bone, and muscle. In addition to their teeth, many carnivores have sharp claws that they use to capture prey. They also use their claws for digging, climbing, and self-defense. Other predator adaptations typically include speed, agility, and keen senses of sight, smell, and hearing.

Not all carnivores feed entirely on meat. Some are like the bear and raccoon, which feed on vegetables and fruits as well as on meat. Such animals are called **omnivores** (om'nə vōrz).

The carnivores include many animals that are well-known. For example, the dog family, which includes coyotes, wolves, jackals, and different domestic breeds, is carnivorous. The cat family, which includes lions, tigers, leopards, cougars, cheetahs, and domestic cats, is also carnivorous. Other common members of this group include otters, badgers, weasles, skunks, wolverines, seals, and walruses.



MAIN IDEA

The carnivores have fangs and sometimes claws. They include omnivores that feed on plants as well as on meat.

SCIENCE BACKGROUND

The panda is a carnivore that feeds exclusively on bamboo shoots in its native land of China. It looks like a bear. It may be a relative of the raccoon or possibly the bear.

The mongoose is an interesting carnivore that is especially skilled at killing snakes. In Southeast Asia it kills the deadly cobra, even though it is not immune to the cobra's poison. It relies upon its speedy reflexes to grab the snake's head and crush it in its teeth.

The fastest land mammal is the cheetah, which differs from all other cats in having non-retractable claws. It is one of the easiest cats to tame, and Indian maharajas used to keep packs of them for hunting antelope.

The cheetah is probably the most specialized member of the cat family. It catches its prey with a great burst of speed over a short distance.



The zebra is a relative of the horse and is a grazing animal. It lives in herds and is often preyed upon by lions.

MAIN IDEA

The ungulates are herbivorous and some, called ruminants, have multiple stomachs.

SCIENCE BACKGROUND

Order *Perissodactyla* includes horses, zebras, tapirs, and rhinoceroses. Order *Artiodactyla* includes all the other ungulates.

32-9 The hoofed animals The mammals with hoofed feet are called **ungulates** (ung'gyə lits). This group actually consists of two orders (order *Perissodactyla* and order *Artiodactyla*). They are classified according to whether they have an odd or even number of toes.

All the ungulates are **herbivorous** (hēr biv'ər əs), or plant eaters, and often graze in herds. They include horses, rhinoceroses, zebras, pigs, camels, bison, llamas, deer, antelope, giraffes, cattle, and sheep. From this list it is easy to see the relationship of the ungulates to humans. For many centuries the ungulates have provided most of the meat in the human diet. Also they have been the principal animals domesticated and used for work and transportation. Only in the parks of Africa do wild ungulates roam in large herds. Once such herds were seen on most continents. Long ago, humans destroyed most of these free-grazing herds.

The ungulates are well adapted for their herbivorous diet. Their teeth are suited for biting off the leaves of plants and shrubs. Their jaws have flat teeth adapted for grinding vegetable matter. Some ungulates, called **ruminants** (rū'mə nənts), have multiple stomachs. The ungulates

swallow their food; then they bring this food back to their mouths for further chewing and grinding.

32-10 Fishlike mammals For years people thought whales, dolphins, and porpoises (order Cetacea) were types of fish. They do look like fish and they swim like fish. Also, like fish, they are capable of remaining under water for long periods of time. But whales, dolphins, and porpoises are mammals, not fish. And they are intelligent mammals at that. Anyone who has seen them perform in marine shows will testify to this fact.

The whales are the largest animals on earth. Back in the days when whales were still plentiful in the ocean, it was possible to see great blue whales over 30 m long. Whales are not plentiful now. Many concerned people in the world community are afraid that they will become extinct due to overhunting.

There are two basic kinds of whales. One group has teeth and feeds on fishes. The other group has a strainer-like apparatus called a whalebone, or baleen. This apparatus strains small crustaceans out of the water. This group of whales is called whalebone whales.

The whale and its relatives have a most amazing adaptation. They have enormous lungs. With this adaptation they can hold their breath for up to an hour. Before they dive they fill the lungs to capacity. Their lungs are almost three times as efficient as ours in obtaining oxygen from the air. Another adaptation is the **blowhole**. This is an opening on top of the whale's head. It acts like the human nose in some ways. It is the place where air enters and waste gases are released. But there are two main differences. When the

MAIN IDEA

The aquatic mammals are intelligent and have highly adapted breathing systems.

SCIENCE BACKGROUND

A terrestrial animal the size of the blue whale would be crushed by its own weight. Studies of dolphins indicate that cetaceans navigate by echolocation. A group of scientists in southern California are now at work with computers and voice tapes of dolphins, trying to devise a way of communicating with them.

Although fishlike in body form, this pilot whale is warm-blooded, gives birth to live young, and nourishes them with milk, making it a member of class Mammalia.



SCIENCE TERMS

mamma
monotremes
marsupials
marsupium
placenta
insectivores
carnivorous
fruit-sucking bats
insectivorous bats
vampire bats
rodents
carnivores
omnivores
ungulates
herbivorous
ruminants
blowhole
primates

MAIN IDEA

The primates have large, complex brains and hands that can grasp. One suborder of primates includes humans and the intelligent apes and monkeys.

SCIENCE BACKGROUND

Many primates are in danger of extinction because of human destruction of their habitat. On the island of Madagascar, where the lemurs live, the natives are rapidly destroying the forests, and it is questionable whether these unique mammals will be able to survive.

whale exhales, a spout of liquid shoots up into the air. This is a mucous solution that is thought to be useful in eliminating unused nitrogen from the lungs. The second difference is that the breathing canal is not connected with the mouth, as it is in other mammals. It bypasses the mouth. This is an important adaptation that allows the animal to open its mouth and feed without taking water into its lungs.

The porpoises and dolphins are smaller than whales. They are playful, friendly animals. Studies of dolphins and porpoises that are confined in marine aquariums show them to have a high level of intelligence.

32-11 The primates Lemurs, monkeys, apes, and humans belong to a major order of mammals called **primates** (prī'mitz) (order Primate). This group has two outstanding adaptations. One adaptation is a large, complex brain. The second adaptation is a flexible hand with a thumb that enables it to grasp.

Theoretically these and other adaptations evolved because of demands on the tree-dwelling ancestors of today's primates. The ability to grasp with the hands offered many advantages for tree dwellers. The development of binocular vision, with both eyes facing forward, greatly increased depth perception. And because of this advancement, the sharpness of the tree dwellers' vision was greatly increased. This, in turn, decreased the necessity for a keen sense of smell. Another key adaptation was the decrease in the number of offspring. They usually gave birth to one or two offspring at a time. These advancements that developed in tree dwellers greatly increased the survival potential of all primates.

There are two suborders of the primates. One (suborder Prosimii) consists of the tree shrew, lemur, bushbaby, and tarsier. These are the most primitive primates. Generally they have not been successful. Their populations are limited to remote regions of Asia and Africa. Many are confined to the large island of Madagascar, which is off the coast of eastern Africa. Most primates in this group have large eyes. But they lack the intelligent expression of the other primates.

The other suborder of primates (suborder Anthrozoidea) consists of monkeys, apes, and humans. Generally the members of this suborder have flattened faces. They also have very complex brains and are the most intelligent of all mammals.

The chimpanzees have been studied more than any other group of primates except humans. There is no ques-



While a few species of primates, such as baboons and gorillas, are primarily ground-dwellers, most primates are arboreal.

tion that they share many human traits. Next to humans they are the most intelligent primates. They can learn and invent. They can be taught to speak a few simple words. In one recent study a young chimp was taught to recognize objects and associate them with over 100 printed words. In addition, the blood reactions and protein structure of chimps are similar to those of humans.

CHECK YOUR FACTS

1. Why have the mammals succeeded in dominating the other animals?
2. List six characteristics of mammals.
3. What are monotremes? How do they nurse their young?
4. How do marsupials differ from other mammals?
5. What is a placenta?

ANSWERS TO CHECK YOUR FACTS

1. They are more intelligent, more adaptable, and warm-blooded.
2. (a) They nurse their young. (b) They have hair. (c) They have fewer skull bones than do birds or reptiles. (d) They have seven neck vertebrae. (e) Their brain is the largest and most highly developed. (f) Usually parents care for their young until adulthood is reached.
3. Mammals that lay eggs. Milk is secreted onto the hair of the mother, and the young lap this milk with their tongue.
4. The young develop while clinging to the mother's nipple, usually in a marsupium.
5. An organ that supplies developing mammals with nourishment from the mother. It is composed of blood vessels from the mother and the developing mammal.

Special Adaptations of Mammals

MAIN IDEA

The integument of mammals is thicker and has more adaptations than the integument of other vertebrates.

MAIN IDEA

Hair is made of keratin and grows from a follicle. A muscle attached to the follicle causes the hair to stand up. Some mammals have both underhair and guard hair.

SCIENCE BACKGROUND

The underhair of aquatic mammals rarely gets wet because of its dense growth.

32-12 Adaptations of the integument The integument of mammals consists of the two layers found in other vertebrates—the epidermis and the dermis. However, the integument of mammals is usually thicker than that of other vertebrates. This gives it more of a protective function. Also the integument has a number of adaptations that further increase the mammals' chances of survival.

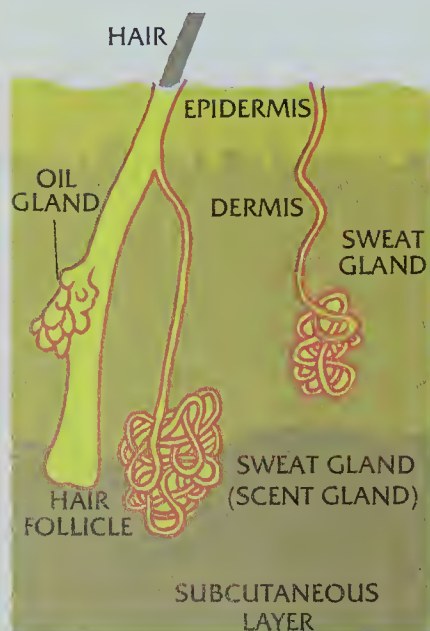
32-13 Hair We have already mentioned that mammals have hair growing out of the integument. Hair is produced by the epidermis. However, it grows from a tubelike cavity, called a **follicle** (fol'ə cəl), which extends down into the dermis. The hair itself grows from living cells inside the follicle, but it is nonliving and is made up of a protein called **keratin** (ker'ə tin).

Attached to the follicle is a small muscle that can contract and cause the follicle to stand upright. If there is a hair in the follicle, it stands upright too. This mechanism allows the hair to trap more air, which, like feather "ruffling" of birds, helps prevent the loss of body heat. The mechanism also works when mammals are angry or frightened. It causes their hair to "stand on end," an adaptation that makes them look larger and more dangerous. The follicles in humans also react to cold and to various emotional states, but all we experience is bumps on the skin called "goosebumps."

Mammals that live in cold climates usually have two types of hair. One type, called **underhair**, is soft and very dense; it insulates the body. The underhair is usually shed, or molted, during the summer. The second type of hair, called **guard hair**, is the outer hair. It is thicker and coarser, and provides more of a protective covering. The guard hair also has various pigments that give mammals their characteristic color. However, most mammals are drab-colored when compared to birds. Their color mainly helps them blend into their surroundings.

FIGURE 32-1

A section of skin from a mammal



32-14 Glands Mammals have in their integument a number of glands that produce secretions. The **sweat glands** produce a weak saltwater solution, which cools the body as it evaporates. Some glands produce oils that keep the hair soft and flexible. Others produce various scents, or chemicals that have a distinct odor. The scents mostly function during mating and for the marking of territories. A **territory** (ter'ə tōr ē) is a space that an animal defends and uses for its own purposes, such as feeding,

mating, or raising the young. Another type of integumentary gland is the mammary gland, which has already been discussed.

32-15 Scales, horns, and antlers Other adaptations of the integument include scales, horns, and antlers. Scales are found on the armadillo and the Asian pangolin. They are of dermal origin and help protect the animal from predators.

Horns are hollow outgrowths of the epidermis and are made of keratin, the protein found in hair, fingernails, and claws. Horns are found on both male and female mammals such as sheep, cattle, and goats. Most horns grow and remain on the head for the life of the animal. The pronghorn antelope is an exception, shedding its horns each year.

Antlers, such as are found on deer and elk, are completely different structures from horns. Antlers are made up of solid bone. Except for reindeer, antlers are found



The armadillo's integument has been modified into protective scales. This animal feeds mostly on insects and is spreading its range northward.

The caribou is a migrating member of the deer family. It is found in Alaska and Canada and feeds on grasses, mosses, and lichens.



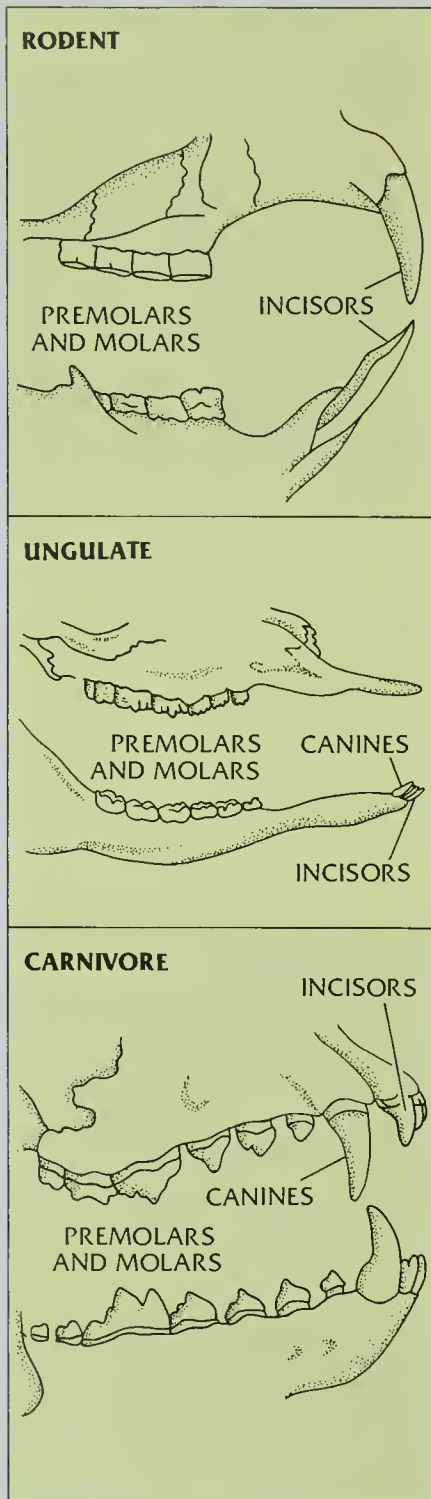


FIGURE 32-2
Compare the different
arrangements of teeth in these
orders of mammals.

only on males and are used during breeding season for defending a territory. Each year, after breeding season, antlers are shed and must be regrown.

32-16 Teeth Most mammals have two sets of teeth during their lifetime. The first set, called **deciduous** (di sij'ù əs) **teeth**, are like the “baby teeth” of humans. They function during the early years of life, then are shed. The second set of teeth, called **permanent** (pēr'mə nənt) **teeth**, normally remain for the lifetime of the mammal.

Mammals have teeth that are specialized for their unique type of eating. **Incisors** (in sī'zərs) are front teeth that are used for biting. Rodents and rabbits have very sharp incisors. The lower incisors of rodents grow constantly and have to be worn down by gnawing. Back of the incisors are the **canines** (ka'nīnz), which are the longest and most sharp-pointed of mammal teeth. The canines are adapted for piercing and are the fangs of the carnivore. **Premolars** (prē mō'lars) are just behind the canines; they are often sharp and are used for cutting and slicing. The **molars** (mō'lars) are farthest back in the jaw and are adapted for brushing and grinding. The molars of herbivores are usually wider and flatter than the molars of carnivores.

Some mammals have highly modified teeth that protrude from the mouth and are called tusks. For example, the elephant has tusks that are very long upper incisors. The wild boar has tusks that are modified canines.

32-17 Adaptations for feeding and digestion The herbivores have one of the most interesting adaptations for digesting food. Their food consists mostly of the polysaccharide called cellulose. Cellulose is a chain of simple sugars that must be broken down during the digestive process. The problem for herbivores is that they do not produce enzymes that can break down the cellulose chains. Instead they must rely on populations of bacteria that live in their digestive tract. In this regard they are like the termites that must depend upon protozoans in their digestive tract. Some herbivores have multiple stomachs with bacteria working on the cellulose in one or more of them. Most herbivores have a blind pouch or tube, called a **cecum** (sē'kəm), that branches off the intestine. The cecum also contains bacteria that digest cellulose. All herbivores have longer digestive tracts than carnivores have. The longer digestive tract allows more time and space for the plant matter to be digested and absorbed.

There is an interesting relationship between the size of a mammal and the food that is required for its survival. The

general rule is, The smaller the mammal, the more food it must eat in relation to its body weight. Shrews, which are the smallest mammals, must eat more than their body weight each day. Without food they will starve within a few hours. On the other hand, large carnivores can go several days without feeding.

There is also an interesting relationship between the feeding time of large herbivores and carnivores. Large herbivores must spend most of their waking hours searching for food and eating. Many large carnivores feed at wide intervals and have much more free time.

32-18 Adaptations for winter Besides their dense growth of underhair, mammals have a number of other adaptations to help them survive the cold winter months. Some, like squirrels, chipmunks, pikas, and mice, store food during the summer or autumn. This food is then used during the cold winter months.

Another adaptation is a type of behavior called **hibernation** (hī bər nā'shən). During hibernation, animals such as ground squirrels and woodchucks go to sleep and their body temperature drops. It may drop to within a degree of the air temperature in the ground where they are

In hibernating mammals, body temperature drops to within a degree of the air temperature, although it will not fall below 0°C.



SCIENCE BACKGROUND

The human appendix is believed to be a remnant of the short cecum that extends beyond the junction of the small and large intestines.

MAIN IDEA

Various mammals adapt to cold winters by storing food; by hibernating, or undergoing prolonged sleep; or by migrating.

SCIENCE TERMS

follicle
keratin
underhair
guard hair
sweat glands
territory
deciduous teeth
permanent teeth
incisors
canines
premolars
molars
cecum
hibernation
estrous cycle
gestation period

ANSWERS TO CHECK YOUR FACTS

1. A tubelike cavity in the integument that contains a hair.
2. A muscle attached to the follicle causes the follicle and the hair to stand up. No, it is made of the protein keratin.
3. Underhair is soft and dense. It insulates the body. Guard hair, or outer hair, is thicker and coarser, and provides a protective covering. Guard hair also contains pigments.
4. Sweat—cools the body; oils—keep the hair soft and flexible; scents—function in mating and in marking territory; milk—food for developing young.
5. Horns are made of keratin and are usually not shed each year. They appear on both sexes. Antlers are bone tissue and are shed each year. They appear primarily on the male only.

MAIN IDEA

The estrous cycle and the gestation period are adapted to allow the young to be born at the most favorable time of the year.

ANSWERS TO REVIEW QUESTIONS

1. They are intelligent, highly adaptable, and warm-blooded.
2. They nurse them with milk from breasts or nipples, and they usually care for the young until they reach adulthood.
3. The monotremes lay eggs. Marsupials give birth to live but poorly developed young that must live on the mother's nipple to survive. The placental mammals develop mostly in the mother and are well developed at birth.

sleeping. However, a mechanism within their body will keep their temperature above freezing. Also during hibernation the heart and respiratory rates both drop. In some cases the heart rate may drop from 150 to 5 beats per minute. Animals that hibernate wake up occasionally to eliminate wastes, but then they go right back to sleep.

Some other mammals, such as certain bears, badgers, raccoons, and opossums, go into what is called a prolonged sleep. This is not a true hibernation. The body temperature drops very little, if at all. Also the animal may awaken several times during the winter and may have periods of considerable activity.

Many mammals migrate between seasons, although their migrations are not as spectacular as those of the birds. In the arctic, great herds of caribou migrate from summer ranges to winter ranges to take advantage of different food supplies. However, the champion migrators are the seals and whales, which live in the oceans and may migrate for great distances.

32–19 Adaptations for reproduction Most mammals are adapted for a seasonal reproductive cycle, with the young born at the most favorable time of the year. Most female mammals have their own unique reproductive cycle, called the **estrous** (es'trəs) **cycle**. The estrous cycle includes the whole series of events associated with egg production and the fertilization of the eggs. The female rat will repeat the estrous cycle every 4 days until she becomes pregnant. The estrous cycle of the cow is 21 days, and of the dog, 6 months. However, for some animals, like the hare and the rabbit, the estrous cycle is continuous, and the female can become pregnant anytime.

The period of time in which the young develop in the female mammal is called the **gestation** (jes tā'shən) **period**. Generally the larger the animal is, the longer the gestation period. For rats the gestation period is 21 days. For cats and dogs it is 60 days, and for the elephant, 22 months.

CHECK YOUR FACTS

1. What is a follicle?
2. Why does hair stand on end? Is hair living tissue?
3. Describe two types of hair found on mammals that live in cold climates.
4. List four products of glands in the integument and state their functions.
5. What are some differences between horns and antlers?

SUMMARY

Because they are intelligent, warm-blooded, and adaptable, the mammals have replaced the reptiles as the dominant animal on earth. Mammals nurse their young and care for them till they reach adulthood. They have hair and other structures in their integument. The mammals have the largest brain and are the most intelligent organisms on earth. Mammals are divided into three groups, based on patterns of development. Most mammals are placental mammals. There are sixteen orders of placental mammals.

REVIEW QUESTIONS

1. Why are the mammals so successful?
2. In what two ways do mammals raise their young differently from other animals?
3. Explain how mammals are divided into three main groups.
4. In which taxonomic order would you find long canine teeth? What mammals do not have teeth?
5. What distinguishes order Carnivora, since many mammals are meat eaters?
6. Describe how the respiratory system of whales is adapted for life in the water.
7. What are the outstanding adaptations that have enabled the primates to survive and succeed? Are all primates successful?
8. What are the functions of the two types of hair? What are they made of? What are follicles?
9. How do glands in the integument benefit the mammal? What is a territory?
10. Distinguish between horns, tusks, fangs, and antlers.

ANALYSIS AND APPLICATION

1. What group of birds has binocular vision like that of mammals?
2. Rank the following mammals in the probable order of their gestation periods.
 - a. jackrabbit
 - b. beaver
 - c. shrew
 - d. goat
 - e. human
 - f. rat
 - g. elephant

4. Order Carnivora . Whale-bone whales.

5. They have long canine teeth and are thus better equipped to eat meat. They also have predator adaptations like claws, speed, and keen sensory abilities.

6. The efficiency and capacity of the lungs are superior to those of other mammals. They have a blowhole, through which unused nitrogen is released from the lungs. Also, the breathing canal bypasses the mouth, allowing them to feed without taking water into the lungs.

7. A large, complex brain; the ability to grasp with the hand; binocular vision; and a decrease in the number of offspring. No, suborder Prosimii includes several unsuccessful species.

8. Underhair insulates the body; guard hair protects the animal and contains pigments. Both types are made of keratin. Follicles are the epidermal cavities from which the hair grows.

9. Glands produce milk to feed the young, scents to mark territory and attract a mate, sweat to cool the body, and oils that keep the hair soft and flexible. A territory is a space an animal defends and uses for its own purposes.

10. Horns are keratin outgrowths of the epidermis. Tusks are modified teeth that protrude from the mouth. Fangs are the long canine teeth of the carnivores. Antlers are structures of solid bone that are part of the integument.

ANSWERS TO ANALYSIS AND APPLICATION

1. Owls.
2. c, f, a, b, d, e, g.

UNIT 6 REVIEW

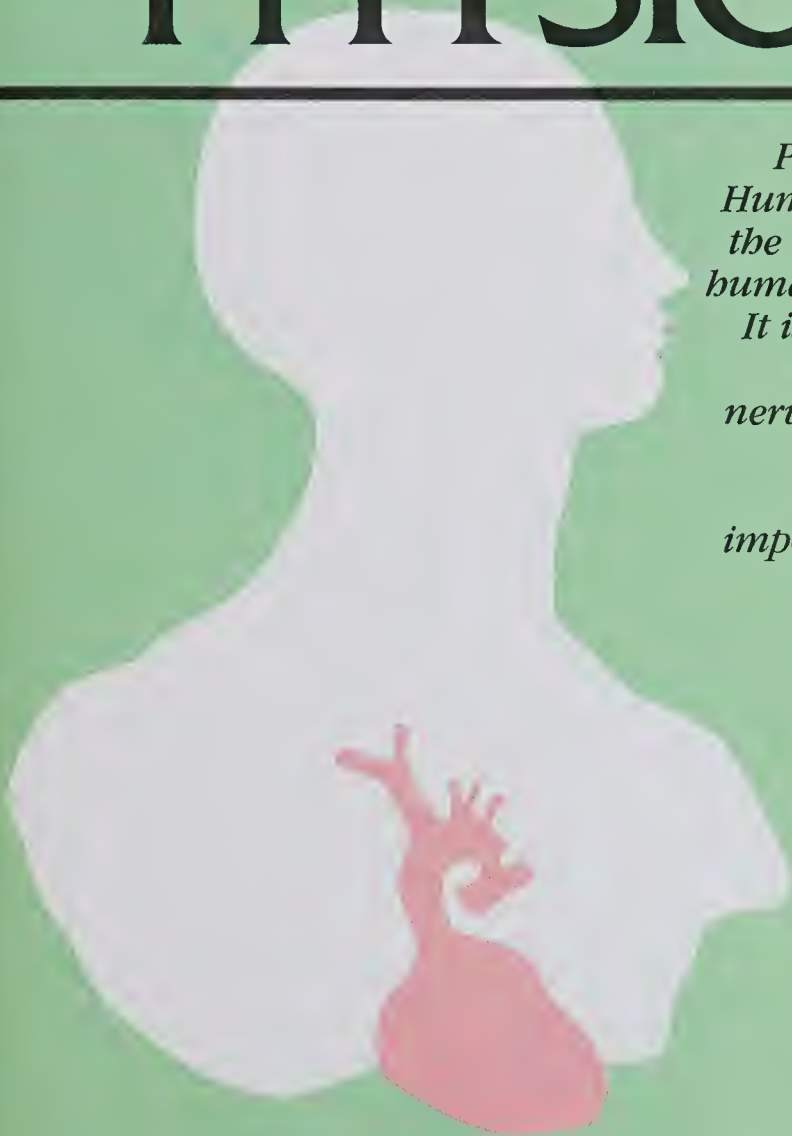
1. What are the distinguishing characteristics of the phylum Chordata?
2. What are the unique characteristics of the subphylum Vertebrata?
3. Fish is an important food source for people in many nations. Prepare a report on the Canadian fishing industry. Include information on the size of the yearly catch, major types of fish caught, and the importance of fish to Canada's food supply.
4. Describe the nature of the circulatory system in amphibians.
5. Find out what frogs, toads, and salamanders are native to your area. If possible, take a field trip to a wooded area and pond, and observe and identify area amphibians.
6. What adaptations in reptiles have enabled them to be more successful in living on land than amphibians?
7. Scientists recognize two orders of dinosaurs, Ornithischia and Saurischia. Prepare a report on the differences between these two orders of dinosaurs. Include comments about specific members of each order.
8. Prepare a report on the habits and habitats of the three poisonous snakes native to Canada. Include in your report identifying features and pictures or sketches if possible.
9. Discuss the characteristics of bird feathers and the basic types of feathers found on birds.
10. Prepare a report on bird migration. Include current information on how birds navigate and factors involved in the timing of migration.
11. Several species of birds are endangered. Prepare a report on an endangered bird species including reasons why it is endangered and steps being taken to protect it.
12. What are the distinguishing characteristics of mammals?
13. Certain mammals that existed during the Ice Age are now extinct. Prepare a report on Ice Age mammals and their adaptations to their environment.
14. Discuss some of the adaptations of mammals that are helpful in surviving through winter.

Unit 7

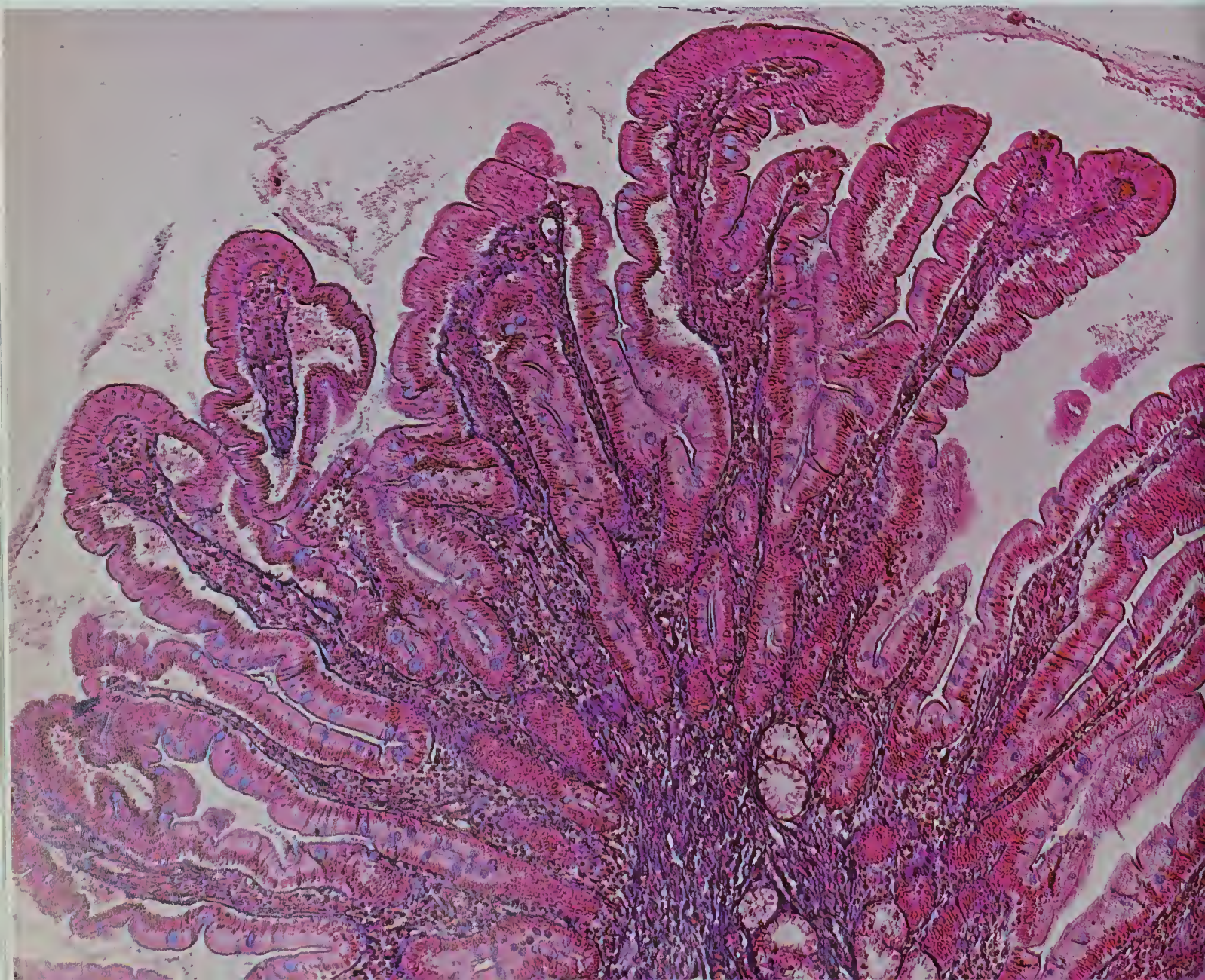
HUMAN PHYSIOLOGY

Physiology is the study of function. Human physiology is the study of how the various organs and systems of the human body carry out their functions.

It is a study of digestion, circulation, breathing, movement, regulation, nervous control, and the mechanisms by which humans reproduce themselves. All these topics are an important part of the general study of biology.



33 *Food and*



OBJECTIVES

- To understand the difference between mechanical and chemical digestion
- To know that the main role of the mouth is to digest food mechanically
- To appreciate that the stomach primarily stores food and completes mechanical digestion
- To understand that most chemical digestion occurs in the small intestine
- To explain the concept of absorption
- To understand that the large intestine absorbs water
- To understand the nature of protein deficiency
- To discuss the role of carbohydrates and fats in nutrition
- To understand the probable cause of and the problems associated with obesity
- To discuss the role of vitamins

Digestion

The First Stages of Digestion

33-1 The digestive system The function of the digestive system is to break down food into the molecular form that can be absorbed into the bloodstream and used by the cells. Proteins are broken down into amino acids. Carbohydrates, which are starches and sugars, are broken down into simple sugars, such as glucose. Fats are broken down into fatty acids and glycerol.

The complete work of the digestive system involves three processes. The first is **mechanical digestion** (mə kan'ə kəl də jes'chən), the physical breakdown of food into small particles. The second process, **chemical digestion**, is the chemical breakdown of carbohydrates, proteins, and fats by digestive enzymes. The third process, by which the products of chemical digestion are moved into the bloodstream, is called **absorption** (ab sôrp'shən).

33-2 The beginning The first process of digestion, mechanical digestion, begins in the mouth. The chewing of food reduces its size and allows it to be swallowed. Chewing allows the food to mix with **saliva** (sə lī'va), a thick liquid that is always present in the mouth.

Saliva performs several functions. It moistens the food and holds it together so that it can be chewed and swallowed. It dissolves some of the food and makes it possible for our taste receptors to function. It cleans the mouth cavity, and it kills some of the harmful bacteria that get into the mouth. In addition, saliva contains an enzyme called

MAIN IDEA

Mechanical and chemical digestion, followed by absorption, provide the body with usable molecules.

SCIENCE BACKGROUND

Mechanical digestion increases the surface area of food that will be exposed for enzyme action. Chewing is especially important for raw fruits and vegetables because it breaks down the nondigestible cellulose that surrounds the digestible food.

MAIN IDEA

In the mouth, food is chewed and acted upon by saliva, which begins chemical digestion of starches.

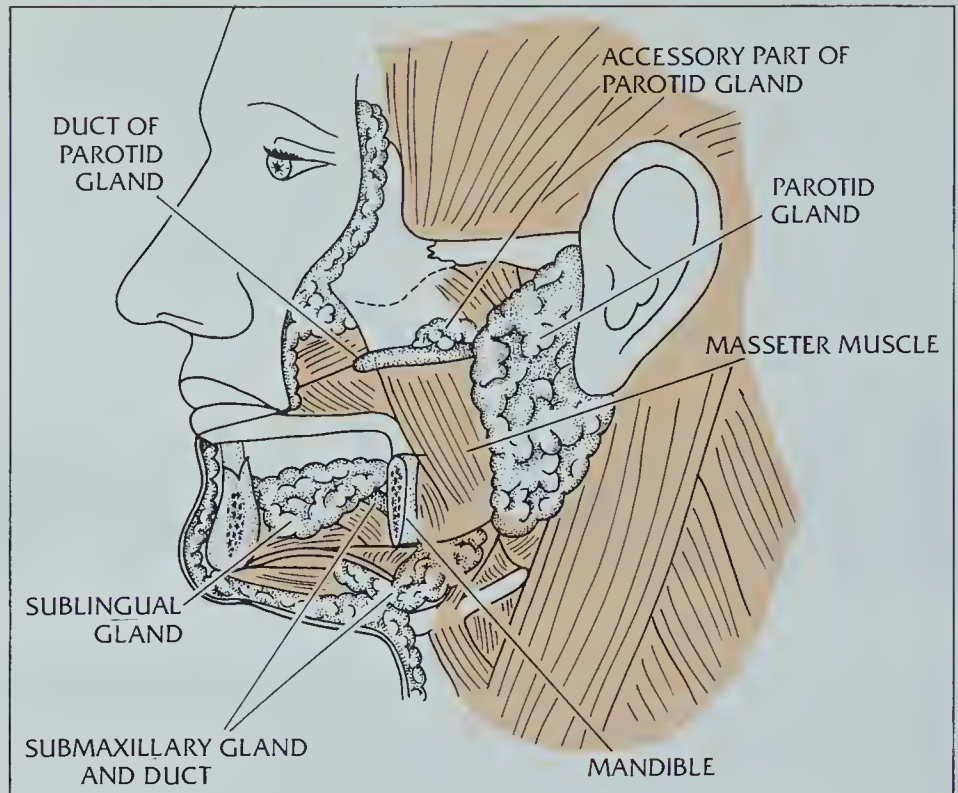


FIGURE 33-1 The locations of the three salivary glands are shown in the illustration above.

salivary amylase (sal'ə ver ē am'ə lās) or **ptyalin** (tī'ə lin), which breaks starches into smaller fragments. The salivary amylase begins the first process of chemical digestion. The process continues in the stomach until the enzyme action is stopped by stomach acid.

Saliva is produced mainly by three pairs of salivary glands that empty, by ducts, into the mouth. The **submaxillary** (sub mak'sə ler ē) glands, which are under the molars in the lower jaw, produce about two thirds of the saliva. The **parotid** (pə rot'id) glands are found just in front of the ears. The third pair, the **sublingual** (sub ling'gwəl) glands, are below the tongue. The salivary glands are more active than most people realize. In an adult they produce 1 to 1.5 L of saliva per day.

MAIN IDEA

Teeth are the principal organs of mechanical digestion. Bacterial enzymes and acids are responsible for caries.

33-3 The teeth The teeth have the most important role in mechanical digestion. In an adult the normal number of teeth includes 8 incisors, 4 canines, 8 premolars, and 12 molars.

The basic structure of a tooth is shown in Figure 33-1. The part of the tooth above the gum is called the **crown**. The part below the gum is the **root**. Between the crown and the root, at the gum line, is the region of the tooth called the **neck**.

The crown is covered with **enamel**, a very hard white material. Under the enamel the internal structure is made up of **dentin** (den'tin), a material similar to bone. Inside the tooth is a cavity called the **pulp chamber**. The pulp chamber contains the nerves and blood vessels that keep the tooth alive. Between the jawbone and the root is a thin membrane, the **periodontal** (per ē ə don'təl) **membrane**, which secretes a hard, bony material called **cementum** (sə men'təm). The cementum surrounds the root and is mainly responsible for holding the tooth firmly in place.

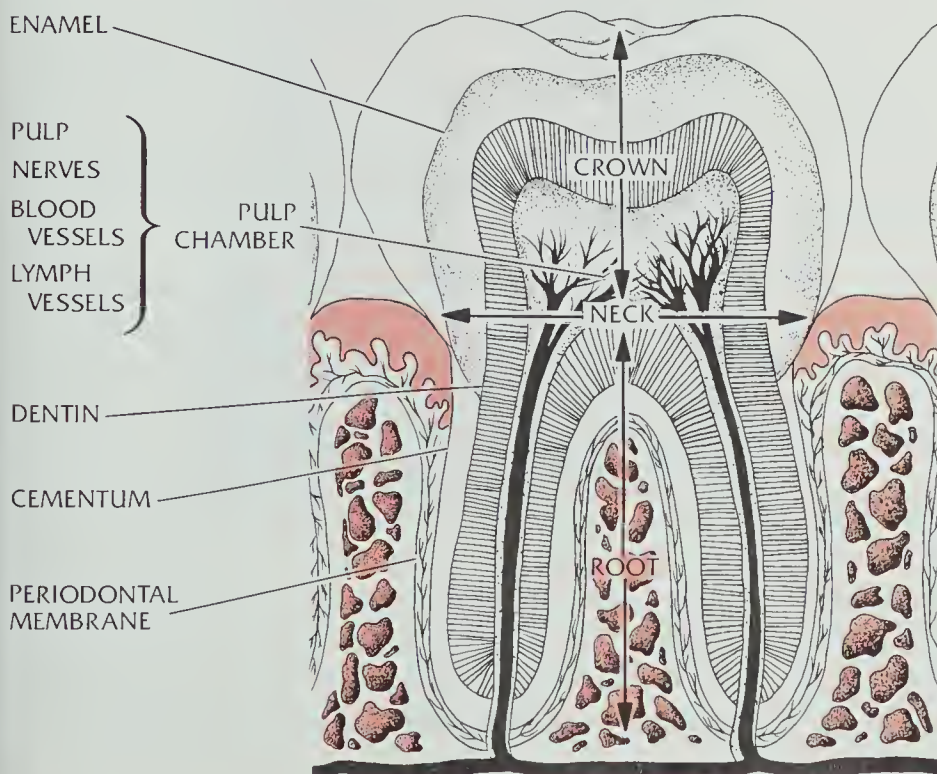
Tooth decay, or **caries** (kār'ēz), is a process that can destroy the teeth. The process starts with the buildup of **plaque** (plak), which are deposits that result from a mixture of food and saliva. Huge populations of bacteria thrive in the plaque. These bacteria produce acids and enzymes that break down the enamel and dentin and cause caries. The bacteria are much more active in the presence of carbohydrates, especially sugars. Prolonged exposure to sugar, as from sucking hard candy, is much worse for the teeth than occasional eating of carbohydrates at mealtime. Proper tooth brushing helps to prevent plaque buildup. However, yearly dental checkups are recommended to prevent plaque buildup, caries, and other dental problems.

SCIENCE BACKGROUND

Tracer studies with radioactive isotopes have shown that the chemicals in teeth are in a constant state of flux as they are in bone. Fluorine treatments have proven effective in preventing caries, but the mechanism is unknown. Fluorine does not make the tooth harder. One hypothesis is that fluorine in the teeth combines with certain tracer elements that are necessary for the activation of bacterial enzymes. This prevents bacterial enzyme action that could cause caries.

FIGURE 33-2

The structure of a tooth is illustrated below. The nerves and blood vessels that supply the tooth are located in the pulp chamber.



SCIENCE TERMS

mechanical digestion
chemical digestion
absorption
saliva
salivary amylase
submaxillary
parotid
sublingual
crown
root
neck
enamel
dentin
pulp chamber
periodontal membrane
cementum
caries
plaque
pharynx
trachea
larynx
epiglottis
Heimlich hug
esophagus
peristaltic waves
sphincter

SCIENCE BACKGROUND

It is strongly recommended that all students learn how to administer the Heimlich hug. Perhaps an ambulance technician or a certified first aid instructor could demonstrate the technique. Knowledge of the technique could enable students to save a person's life.

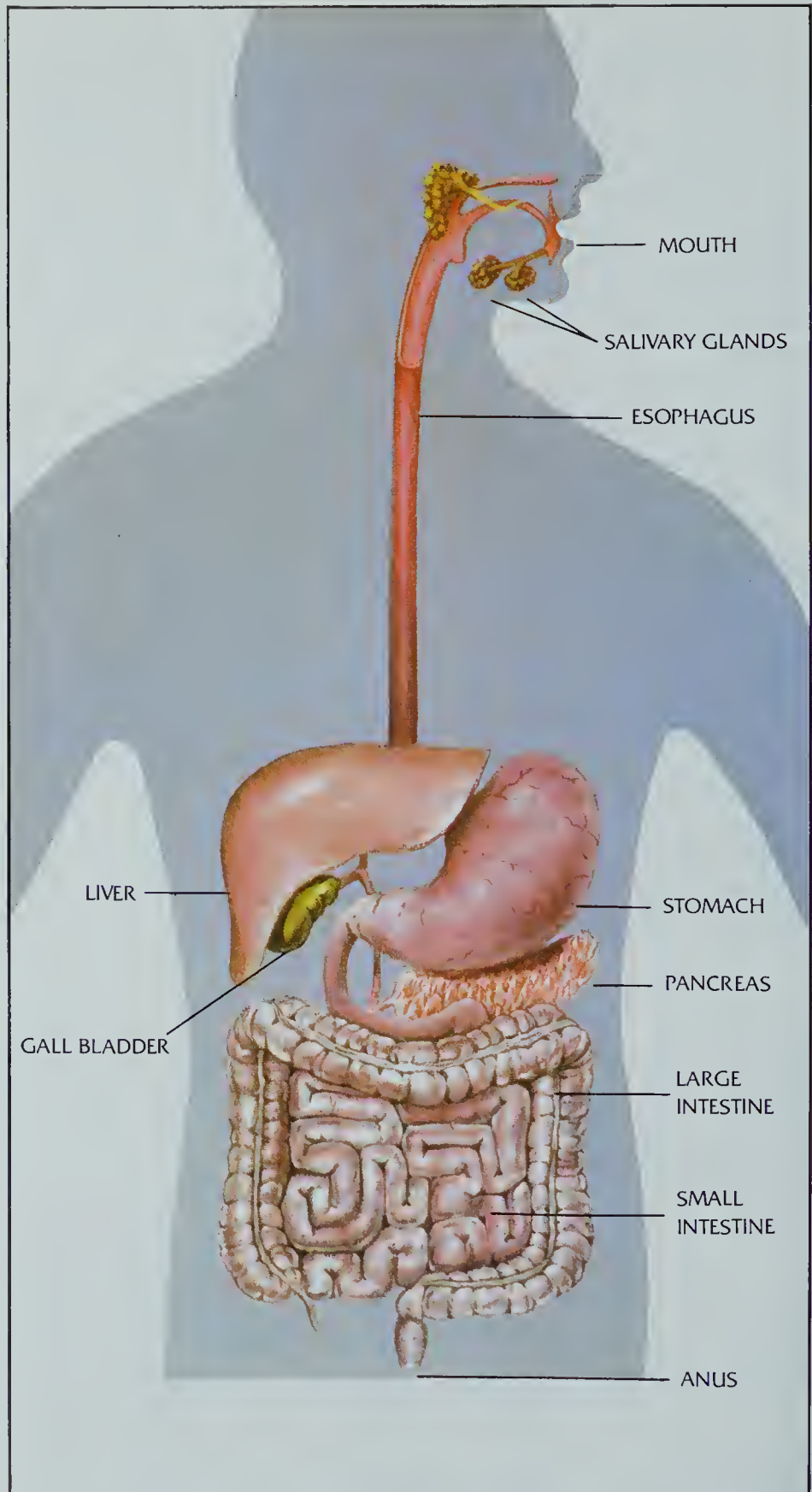


FIGURE 33-3 The human digestive system and the major organs associated with it

33-4 Swallowing Food leaves the mouth and starts on its way to the stomach by the process of swallowing. On this route, food first passes through the throat, or **pharynx** (far'ingks), which is a funnel-shaped tube. Here a problem can arise because the pharynx is a dual pathway. Air from the nose also moves through the pharynx into the **trachea** (trā'kē ə), or windpipe. Normally we have a process that keeps the flow of air and food separated. When we swallow, the voice box, or **larynx** (lar'ingks), moves upward. (Place a finger on your "Adam's apple" and you can feel it move upward when you swallow.) There is a small flap on the larynx, called the **epiglottis** (ep ə glot'is). This flap usually prevents food from entering the trachea as it passes down the throat.

Sometimes accidents happen and food becomes stuck in the opening of the trachea. This prevents air from entering the lungs, which causes choking. Often the food is forced out of the trachea by coughing. However, if the food should remain, the choking victim may die. The person cannot speak or breathe and can die within a very short time. If choking occurs, the victim can be saved by the standard first aid procedure called the **Heimlich hug**. This procedure is illustrated in Figure 33-4.

33-5 The esophagus After food leaves the pharynx it enters the **esophagus** (ē sof'ə gəs), which is a muscular tube. Once in the esophagus, food is pushed along by waves of muscle contraction called **peristaltic** (per ə stal'tik) **waves**. They keep the food and the wastes of digestion moving through the remainder of the digestive tube. Water will move through the esophagus in about one second. However, if a large firm wad of food is swallowed, it may require as long as nine seconds before it reaches the stomach.

About 5 cm before the esophagus joins the stomach, there is a ring of muscles that act as a **sphincter** (sfingk'tər). A sphincter is a type of valve that closes and opens by the squeezing and relaxing of muscles. The sphincter in the esophagus keeps material in the stomach from coming back up the esophagus when the stomach muscles contract. (The sphincter is forced open during vomiting, when food is forcefully expelled from the stomach.) The esophagus is not lined with the protective coating found in the stomach. Therefore enzymes, helped by strong acid from the stomach, could digest the wall of the esophagus and create a sore, which we shall describe later in the chapter.



FIGURE 33-4

Food that is lodged in the trachea may be forced out by administering a procedure known as the Heimlich hug.

MAIN IDEA

Food travels from the pharynx to the stomach by the peristaltic waves of the esophagus. The sphincter at the base of the esophagus acts as a valve to prevent food from leaving the stomach toward the mouth.

SCIENCE BACKGROUND

The gastroesophageal sphincter is not anatomically different from the rest of the esophagus. Rather it is technically called a physiological sphincter because that section of the esophagus has the unique sphincter function.

ANSWERS TO CHECK YOUR FACTS

1. To break down food into the molecular form that can be absorbed into the bloodstream and be used by the cells.
2. Mechanical digestion, chemical digestion, and absorption. Mechanical and chemical digestion.
3. It holds the food together so that it can be chewed. It dissolves some food, allowing taste receptors to function. It wets the mouth, making speech possible. It cleans the mouth and kills some harmful bacteria. It begins the chemical digestion of starches.
4. In the submaxillary glands under the molars of the lower jaw; in the parotid glands in front of the ears; and in the sublingual glands beneath the tongue.
5. Between the jawbone and the root of the tooth. It secretes cementum that surrounds the root and holds the tooth firmly in place.

MAIN IDEA

The stomach stores food, mechanically digests it with muscular contractions, and chemically digests it with pepsin and hydrochloric acid.

SCIENCE BACKGROUND

The stomach has two main regions: the body, or corpus, and the antrum. The corpus includes most of the stomach. The antrum is the region near the pylorus and is more muscular.

CHECK YOUR FACTS

1. What is the function of the digestive system?
2. What three processes are involved in digestion? Which occur in the mouth?
3. What are the functions of saliva?
4. Where is saliva produced?
5. Where is the periodontal membrane located? What is its function?

The Role of the Stomach

33-6 Structure of the Stomach The stomach is an enlarged part of the digestive tube. When it is empty its walls are almost touching, and there is very little space inside. After eating, the stomach stretches and will hold a volume of about 1 L.

Food enters the stomach from the esophagus through an opening called the **cardia** (kār'dē ə). The other opening, called the **pylorus** (pī lôr'əs), is between the stomach and the small intestine. At the pylorus is a ring of muscles called the **pyloric sphincter**, which controls the movement of materials into the small intestine.

The walls of the stomach are made up largely of muscles that run in different directions. These are **smooth muscles**, which are involuntary and are of the type found in the walls of the entire digestive tract. The inside of the stomach is lined with cells that secrete gastric juices. The gastric juices include a variety of chemicals that help the stomach perform its functions.

33-7 Functions of the stomach One function of the stomach is to store the large quantity of food that is often consumed at a meal. The stomach also has two digestive functions. First, it completes the mechanical digestion that was started in the mouth. The peristaltic waves help in mechanical digestion by squeezing the stomach. This mixes the food with the gastric juices and results in a pasty fluid called **chyme** (kīm). The food particles in the chyme become smaller and smaller, greatly increasing the surface area that is exposed to enzyme action.

The second function of the stomach is to begin the chemical digestion of proteins. This process requires two chemicals, both of which are secreted by cells in the stomach lining. One chemical is the enzyme **pepsin** (pép'sin). This enzyme breaks protein molecules down into shorter chains of amino acids called **peptides** (pép'tīdz). The

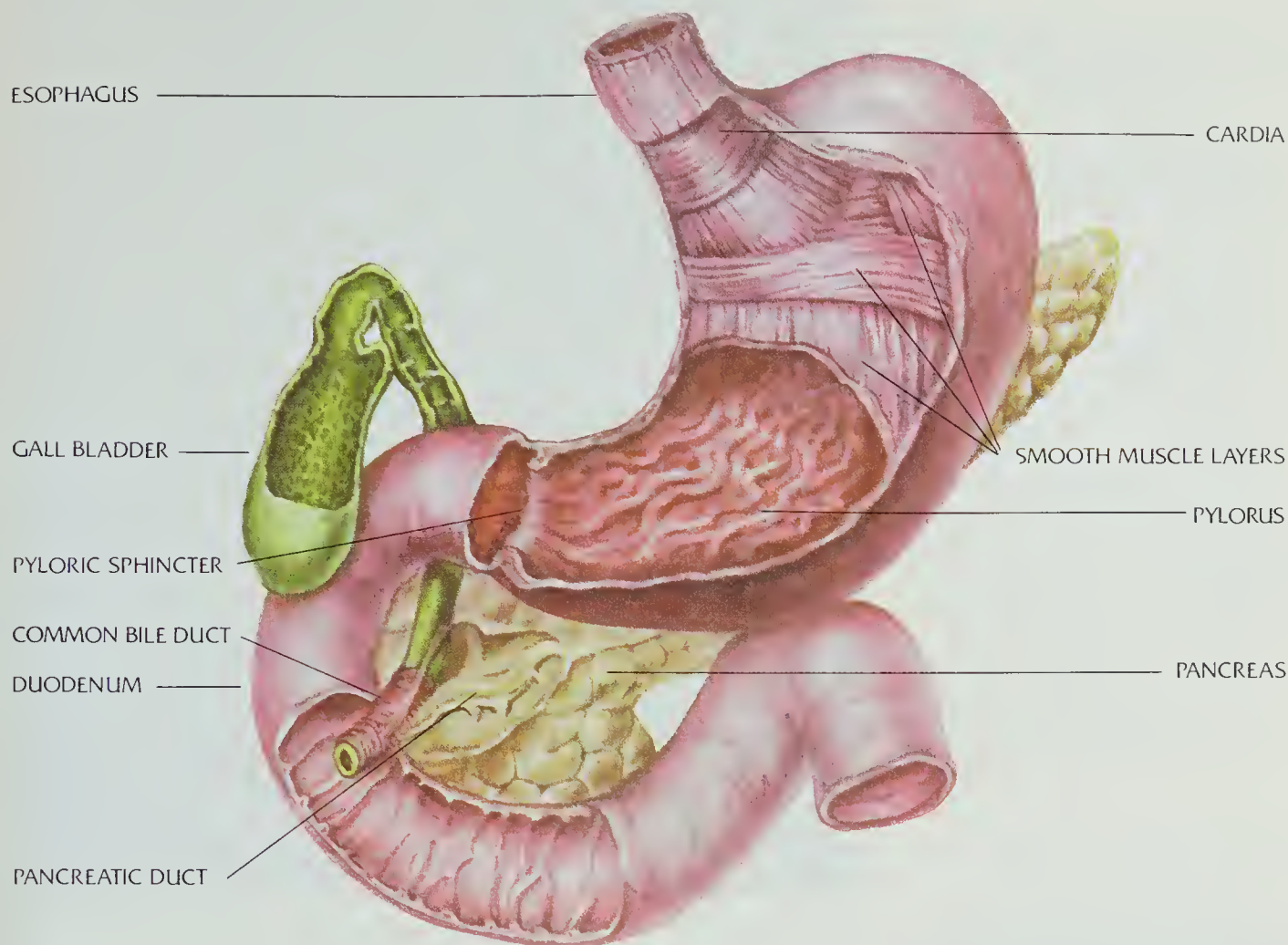


FIGURE 33–5

The stomach wall consists of three layers of smooth muscle. Mechanical digestion is completed by contractions of these muscles.

second chemical is **hydrochloric acid**, which makes it possible for the pepsin to function. Unless pepsin is in a strong acid solution, it cannot function as an enzyme.

33–8 Protection of the stomach Why doesn't the stomach digest itself? It does not because it is protected by a thick, sticky substance called **mucus** (myü'kəs). The mucus is produced by some of the cells that line the stomach and it forms a layer that is 1 mm or more thick. Mucus is also produced by cells in the lining of the small and the large intestines, where it serves the same function.

Sometimes the mucus fails to protect the wall of the stomach. When this occurs, pepsin begins to digest part of the wall, creating a sore called a **peptic ulcer** (pep'tik ul'sər). Peptic ulcers can also occur just inside the **duodenum** (dü ə dē'nəm), which is the first section of the small intestine. They are caused by pepsin that is in the chyme when it leaves the stomach. This variety of peptic ulcer is

MAIN IDEA

The stomach is protected by mucus. When this protection fails, a peptic ulcer can result.

The aroma produced by food as it cooks over a fire may stimulate the appetite of a person nearby.

SCIENCE TERMS

cardia
pylorus
pyloric sphincter
smooth muscles
chyme
pepsin
peptides
hydrochloric acid
mucus
peptic ulcer
duodenum
hunger
appetite

SCIENCE BACKGROUND

Actually the stomach has two mechanisms for protecting itself and for preventing absorption of ingested materials. Besides the mucus, the tall columnar epithelial cells are very close together and are joined at the apex to provide a strong barrier. Alcohol is the only commonly ingested substance (other than water) that can penetrate the barrier and be absorbed.

MAIN IDEA

Hunger is a physical desire for food based on need. Appetite is a psychological desire based on past experience.



called a duodenal ulcer. Peptic ulcers also develop occasionally in the lower part of the esophagus. They are caused by a backward flow of chyme.

Many people think that ulcers are caused directly by excess stomach acid. In a way they are, but the acid is only the indirect cause. The acid only makes it possible for the pepsin to digest the tissue. The pepsin is the direct cause of the ulcer. Treatment for ulcers includes antacid medicines that neutralize the hydrochloric acid and prevent pepsin from working.

33-9 Hunger and appetite About 12 to 24 h after eating, the stomach begins a series of strong contractions. These cause a mild pain sensation and are called "hunger pangs." The hunger pangs create a strong desire for food, a desire called **hunger**.

Appetite (ap'ə tīt) is entirely different from hunger. Appetite is the psychological desire for one or more types of food. It is based on experience. For example, after once having eaten fried chicken, many people can develop an appetite for fried chicken. They can develop the appetite

by smelling it, by hearing someone talk about it, or by thinking about it.

CHECK YOUR FACTS

1. What is the pyloric sphincter and what does it do?
2. Where are the cardia and the pylorus located?
3. What are the involuntary muscles that make up the digestive tube called?
4. Describe mechanical digestion in the stomach.
5. What chemical digestion occurs in the stomach?

ANSWERS TO CHECK YOUR FACTS

1. A ring of muscles at the pylorus. It controls the passage of materials from the stomach to the small intestine.
2. The cardia is the opening from the esophagus into the stomach. The pylorus is the opening in the stomach that leads to the small intestine.
3. Smooth muscles.
4. Peristaltic waves mix the food with gastric juices, resulting in a pasty substance called chyme. This reduces the size of food particles, thus increasing their surface area.
5. Pepsin breaks down proteins into peptides. Hydrochloric acid is also present to enable the pepsin to function.

The Small and the Large Intestines

33–10 The small intestine There are three regions of the small intestine, which, in total length, average about 5 m. The first region, the duodenum, is by far the shortest. It is about 20 cm long. The other two regions are the **jejunum** (ji jū'nəm) and the **ileum** (il'ē əm).

On the inside wall of the small intestine there are ridges that increase the surface area about 3 times. On the ridges there are millions of small projections called **villi** (vil'i). The villi are about 1 mm long and wave back and forth. The villi increase the surface area about 10 times. In addition, the cells that line the surface of the villi have projections called **microvilli** (mi'krō vil'i). The microvilli increase the surface area about 20 times. Together the ridges, villi, and microvilli increase the inside surface area of the small intestine about 600 times. This area is estimated to be about 250 m², which is larger than the floor area of most homes!

33–11 Function of the small intestine Most of the chemical digestion and practically all of the absorption occurs in the small intestine. Two organs assist with the digestion. The liver, which is the largest organ in the body, produces **bile** (bīl). The bile is stored in a container called the **gallbladder** (gōl blad'er). The bile helps digest fats. The other organ is the **pancreas** (pan'krē əs), which is long and thin and lies behind and slightly below the stomach. The pancreas produces enzymes that digest carbohydrates, proteins, and fats.

33–12 Digestion of carbohydrates Carbohydrate digestion is started by salivary amylase, but acid in the stomach eventually stops that process. It starts again



FIGURE 33–6

The villi and microvilli lining the walls of the small intestine greatly increase the surface area available for absorption.

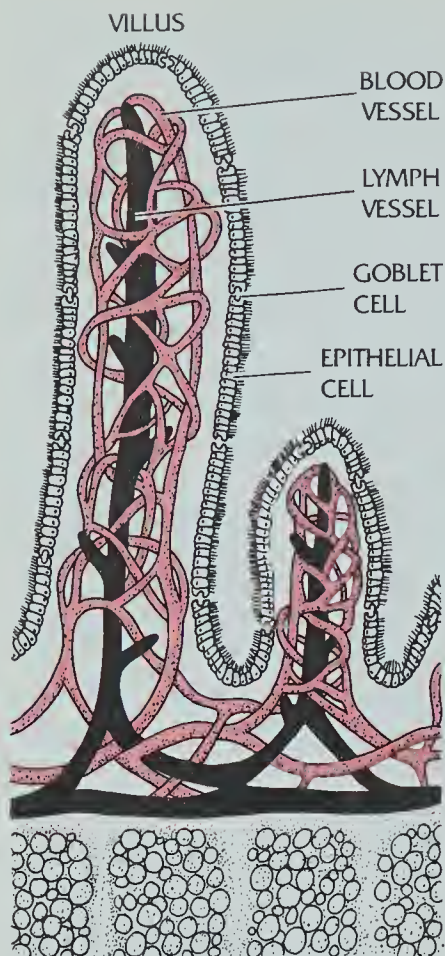


FIGURE 33-7

Simple sugars and amino acids are absorbed into the capillaries of the villi. Glycerol and fatty acids, as triglycerides, enter lymph vessels.

MAIN IDEA

Bile transforms fat into tiny droplets, which are digested by pancreatic lipase, with assistance from the microvilli.

MAIN IDEA

Simple sugars and amino acids are absorbed into the bloodstream after being actively transported into the cells lining the villi. Glycerol and fatty acids enter the lymphatic system after passing through the villi.

when carbohydrates reach the duodenum. There an enzyme similar to the one in the saliva, called **pancreatic** (pan krē at'ik) **amylase**, breaks starches into disaccharides (dī sak'ə rīdz), or double sugars, and monosaccharides (mon ə sak'ə rīdz), or simple sugars. Glucose makes up about 80 percent of the simple sugars that result from carbohydrate digestion. Also assisting in the digestion of carbohydrates are some enzymes in the microvilli of the small intestine.

33-13 Digestion of proteins Pepsin in the stomach starts protein digestion, but the acid necessary for the pepsin to function is neutralized in the duodenum. Most of the proteins have been broken down into peptides—short chains of amino acids—when they reach the duodenum. The peptides are then acted upon by three different **proteases** (prō'tē ās es) that are secreted by the pancreas. *Protease* is the general name for any protein-digesting enzyme. The proteases continue to break peptide bonds, which are the bonds that link the individual amino acids to each other. They are assisted by proteases in the microvilli.

33-14 Digestion of fats Fats are harder to digest than carbohydrates or proteins. The body solves this problem by treating the fats with bile so that the digestive enzymes can do their work. The bile acts like dishwashing detergent does on grease-covered dishes. The detergent breaks down the fat into small droplets that can be washed off with water. The bile breaks down the fat in the small intestine into the same tiny droplets. In this form, the fat-digesting enzymes can attach to the droplets and break them down further.

The main enzyme that breaks down fats is produced by the pancreas. It is called **pancreatic lipase** (lī'pās). *Lipase* is a general name for any enzyme that breaks down fats or fat-related chemicals.

Most fats in our food are triglycerides, which consist of glycerol and three fatty acids. The digestive process breaks down the triglyceride into those separate molecules. As with the other food molecules, a lipase in the microvilli also helps digest the fats.

33-15 Absorption in the small intestine The main end products of digestion are simple sugars (mostly glucose), amino acids, glycerol, and fatty acids. To be absorbed these molecules must first pass into the cells that line the villi. However, all the molecules are too large to diffuse through the cell membranes. So other methods of

transport are used. The simple sugars and amino acids pass through the cell membranes by active transport. Glycerol and fatty acids probably pass through the membranes by being dissolved in the lipid layer of the cell membrane.

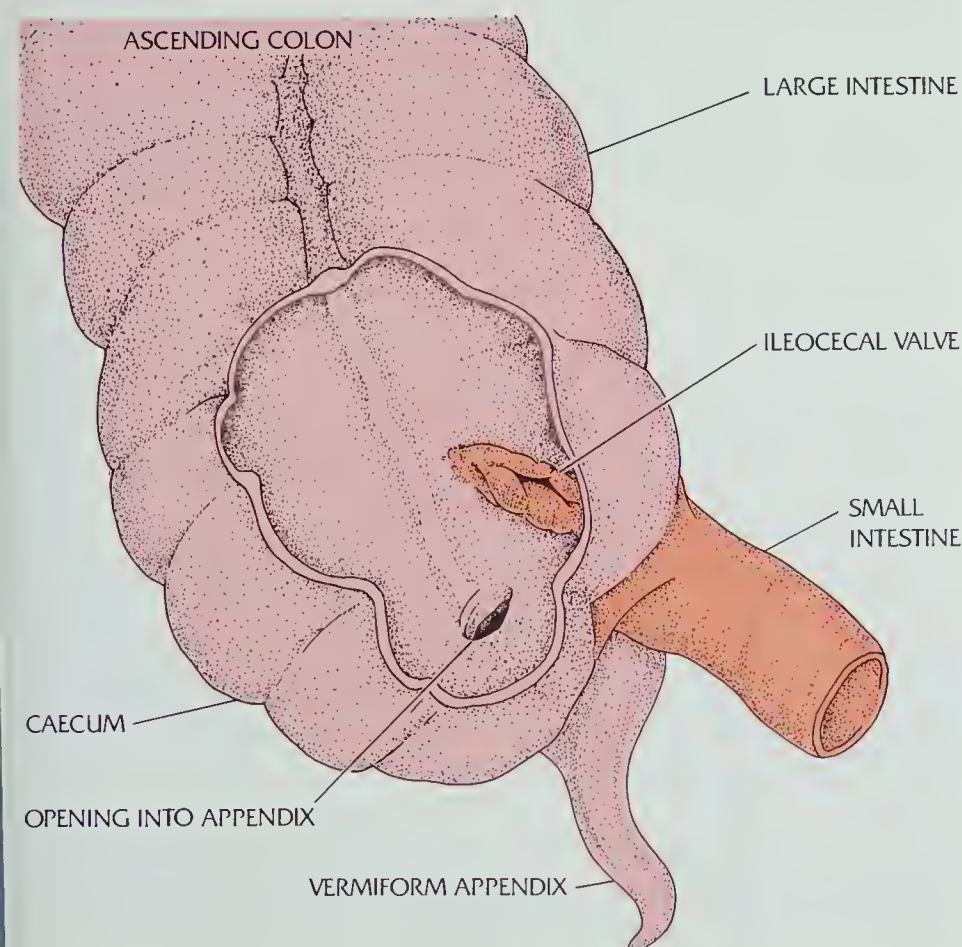
Lipids are organic compounds that include fats, oils, and waxes. Lipids make up the middle of the cell membrane.

From the lining cells the simple sugars and amino acids pass into capillaries in the villi. This route puts them directly into the bloodstream. The glycerol and fatty acids take another route. First, they are resynthesized into triglycerides, or fats. This occurs in the endoplasmic reticulum of the lining cells. A protein coat is synthesized around the small droplets of the newly formed fat. These then enter the lymphatic system.

33-16 The large intestine The large intestine, or **colon** (kō'lən), is much shorter than the small intestine. It is called the large intestine because it is larger in diameter.

A sphincter at the junction of the small intestine and the colon controls the movement of materials into the colon.

FIGURE 33-8 The ileocecal valve controls the flow of materials from the small intestine into the colon or large intestine.



SCIENCE TERMS

jejunum
ileum
villi
microvilli
bile
gallbladder
pancreas
pancreatic amylase
proteases
pancreatic lipase
lipids
colon
defecation
anal sphincter

MAIN IDEA

Absorption of water, vitamins, and some ions occurs in the colon. The colon also stores waste materials that become feces.

SCIENCE BACKGROUND

The regions of the colon are, in order, the ascending colon, transverse colon, descending colon, sigmoid colon, and rectum. There are no villi in the colon, but there are a number of pits where absorption occurs. The colon is heavily lined with mucus, which protects and lubricates.

Other vitamins produced by bacteria are B₁₂, thiamin, and riboflavin.

There are actually two anal sphincters. The internal anal sphincter has smooth muscle and is under involuntary control. The external anal sphincter surrounds the internal anal sphincter and lies slightly distal. It is made up of striated muscle and is under voluntary control.

ANSWERS TO CHECK YOUR FACTS

1. The duodenum, the jejunum, and the ileum.
2. Most chemical digestion and nearly all absorption.
3. It is produced in the liver and stored in the gallbladder. It breaks fats into small droplets.
4. Proteases, pancreatic lipase, and pancreatic amylase. It is behind and a little below the stomach.
5. Salivary amylase digests some carbohydrates in the mouth. Digestion is resumed in the duodenum, where pancreatic amylase and enzymes from the microvilli complete the breakdown into simple sugars.

MAIN IDEA

Malnutrition is the condition that results when essential foods are missing from the diet.

MAIN IDEA

During a protein deficiency, body tissues are digested to provide amino acids for the essential body functions. Essential proteins must be obtained in the diet. Protein deficiency during pregnancy can cause mental retardation in the child.

The colon has two main functions. One function is absorption, which occurs mainly in the first half of the colon. Water and certain ions, such as sodium and chloride ions, are absorbed. Certain vitamins, produced by bacteria in the colon, are also absorbed. This is our most important source of vitamin K, the vitamin that helps our blood clot.

The second function, which uses the last half of the colon, is storage. The material being stored is the waste material from digestion, which will become feces. The feces are made up mostly of dead bacteria and undigested food. The feces are released through the anus by the process of **defecation** (def ə kă'shən). Defecation can be controlled by the last sphincter in the digestive tube, the **anal sphincter**.

CHECK YOUR FACTS

1. What are the three regions of the small intestine?
2. What parts of the digestive process occur in the small intestine?
3. Where is bile produced and stored? What does it do?
4. Name some products of the pancreas. Where is it located?
5. Describe digestion of carbohydrates.

Human Food Needs

33-17 The basic six Human food needs fall into six categories: proteins, carbohydrates, fats, minerals, vitamins, and water. Getting enough water is rarely a problem, so we shall discuss only the other five.

Nutrition (nü trish'ən) is the special science that tries to determine the food needs of people and other organisms. **Malnutrition** (mal nü trish'ən) is the condition that results when one or more essential foods are missing from the diet. Malnutrition can cause disease. Severe malnutrition can cause death by starvation.

Malnutrition sometimes occurs even when people have access to essential foods. Such malnutrition is caused by the improper selection of foods. In other words, the essential foods may be available, but they are not selected and eaten for some reason. The lack of knowledge might be one cause. That is why it is important for every person to know what foods the body needs.

33-18 Proteins When a diet lacks proteins, the body turns upon itself and begins to digest the proteins in its own tissues. It uses the amino acids to build body pro-

Table 33–1 The Basic Nutrients

<i>Nutrient</i>	<i>Good Sources</i>	<i>Functions</i>	<i>Effect of Deficiency</i>
Carbohydrates	sugar, bread, cereals, potatoes, rice, pasta, fruit	supply energy	lack of energy, loss of weight
Fats	butter, lard, margarine, nuts, oils, red meats	supply energy, protect the body, essential for many life processes	lack of energy, loss of weight
Proteins	complete—fish, meat, poultry, eggs, milk, cheese incomplete—dried peas and beans, lentils, nuts, cereals	promote growth and tissue repair, resistance, enzymes	retarded growth, low resistance, lack of energy, poor body functioning

SCIENCE BACKGROUND

It is important to stress that pregnant mothers should be careful to include abundant complete proteins in their diet.

Kwashiorkor is a severe protein deficiency disease. In children it results in a protruding belly, which is caused by the improper development of the abdominal muscles.

The 8 essential amino acids are leucine, lysine, threonine, isoleucine, tryptophan, valine, methionine, and phenylalanine.

teins that are the most essential for life. During a protein deficiency some of the first tissues that are used are the muscles. That is why starving people look as if they are nothing but “skin and bones.” Other body tissues that are digested during a protein deficiency are the blood proteins that make antibodies. Antibodies protect us from infectious diseases that are caused by bacteria and viruses. Therefore a person with a protein deficiency can catch any number of infectious diseases.

The proteins in our food are primarily tissue builders. The amino acids that they provide are used to make all the different body proteins. But 8 out of the 20 amino acids that are found in proteins are called **essential amino acids**. An essential amino acid is one that cannot be synthesized by the body.

All essential amino acids must be available to the cell’s protein synthesis machinery before there is any attempt to

make a protein. If only 7 of the essential amino acids are present, the cell does not make part of a protein and wait until the eighth appears. The lack of any one essential amino acid shuts down the protein synthesis machinery.

What about the other 14 of the 20 amino acids? The other 14 amino acids can be synthesized out of raw materials such as nitrogen compounds or other amino acids.

In foods, proteins that contain all 8 essential amino acids are called **complete proteins**. Eggs, milk, and meats are our most complete proteins. **Partial proteins** are those that lack one or more of the essential 8 amino acids. Zein, which is the protein in corn, is an example of a partial protein. In cultures where the diet is mainly corn and is not supplemented with other foods, the children are most seriously affected. They can suffer various diseases, mental retardation, and stunted growth. Generally meat and dairy foods have more complete proteins than vegetables.

Pregnancy is a critical time when complete proteins *must* be included in the diet. Recent studies indicate that incomplete brain development and mental retardation can result when a pregnant mother does not have enough complete proteins. What is worse, those conditions cannot be reversed after the birth of the child.

MAIN IDEA

Carbohydrates provide the body with most of its energy. Because they are easily available, carbohydrate deficiency is rare.

33-19 Carbohydrates An extremely small amount of carbohydrates is essential in the body. However, our diet usually contains enough carbohydrates to take care of those needs. Carbohydrates are our cheapest food and they are most useful as a fuel to provide energy. It was mentioned earlier that about 80 percent of our carbohydrates are broken down into the simple sugar glucose. The glucose provides energy when it is broken down in the process called respiration.

Carbohydrates are not the sole source of energy. Fats and amino acids are also broken down to provide energy. The typical supply of body energy is estimated as follows: carbohydrates—58 percent, fats—30 percent, proteins—12 percent.

The energy value of any food is measured in the amount of heat it will produce when burned in oxygen. The heat energy that is released is measured in units called **kilojoules**. A kilojoule represents the amount of energy which, when added to 1 kg of water, will raise the temperature of the water by 4.2°C.

MAIN IDEA

Fat deficiency is rare. Excess fat is stored in adipose tissue and can cause obesity.

33-20 Fats Like carbohydrates, some fats are essential in the body. However, such a small amount is needed that fat malnutrition is rare. Fats are primarily of value for the energy that they supply.



Grains, such as wheat, are an important source of carbohydrates. Carbohydrates supply energy for life processes.

Most carbohydrates that are not needed for energy are converted by the body into fat. Fat is stored in a special kind of tissue called **adipose** (ad'ə pōs) **tissue**. A quantity of adipose tissue far in excess of what the body is likely to need causes **obesity** (o bē'sə tē).

33–21 Obesity and diet Obesity is an unhealthy condition of the body. Studies show that obese people are much more likely to suffer from heart disease, diabetes, gallbladder disease, and several other diseases. On the average, obese people do not live as long as people with more normal weights. Also obese people have more problems carrying out physical activities. The excess weight makes physical movement more difficult. The excess fat also makes it difficult for the body to cool itself. Therefore physical activity causes more sweating and discomfort.

SCIENCE TERMS

nutrition
malnutrition
essential amino acids
complete proteins
partial proteins
calories
adipose tissue
obesity
anemia
vitamins

SCIENCE BACKGROUND

Other elements that are seldom in short supply are sodium, potassium, magnesium, copper, sulfur, and chloride ions. Also a number of elements are needed in only trace amounts.

MAIN IDEA

Obesity is detrimental to the body in many ways. It is caused by burning up fewer calories than are consumed.

A proper diet along with regular physical exercise can help control weight and contribute to overall health.

ANSWERS TO CHECK YOUR FACTS

1. Proteins, carbohydrates, fats, minerals, vitamins, and water. Proteins.
2. The science that determines the food needs of people and other organisms. The condition that results from lack of essential foods in the diet.
3. The body digests such tissues as muscles and blood proteins. These blood proteins make antibodies that resist diseases, thus a protein deficiency can lead to the reduction of the body's defense against disease.
4. An amino acid that is not produced by the body. It must be obtained from the food that is digested.
5. Proteins in foods that contain all the essential amino acids.

MAIN IDEA

Iron, calcium, phosphorous, and iodine are some of the essential minerals.

MAIN IDEA

Vitamins are chemicals that are not produced by the body but are required in minute amounts. A varied diet easily supplies the essential vitamins needed by a normal person.



Obesity occurs when a greater number of calories are eaten than are burned by the body. There are three possible causes for such an imbalance. One is overeating. The second is a lack of physical exercise, which burns up calories. The third, which is thought to be much less common, is a problem with hormones.

33-22 Minerals Many different minerals are needed by the body. But only a few are likely to be of concern in selecting foods to eat. One is iron, which is one of the important elements in hemoglobin, our oxygen carrier in the blood. The lack of iron can cause **anemia**, a disease that causes tiredness and other problems.

Calcium and phosphorous are two minerals that are often found together in food. Calcium is especially important for the proper development and continued health of teeth and bones. Phosphorous is needed in every cell of the body. It is found in ATP, DNA, and RNA.

Iodine is another element that could be lacking in the diet. It is needed by the thyroid gland to produce one of its hormones. Iodine is now added to salt and is called iodized salt.

33-23 Vitamins Vitamins are chemicals that are not manufactured by the body but are needed in small amounts before certain functions can be performed. Almost any diet that includes meats and vegetables, including fresh, leafy vegetables, will have enough of the vitamins

Table 33–2 Minerals

<i>Mineral</i>	<i>Good Sources</i>	<i>Functions</i>	<i>Effect of Deficiency</i>
Iodine	shellfish, saltwater fish, iodized salt	formation of thyroxin, regulation of the cells' use of energy	thyroid disorders
Magnesium	milk, meats, whole-grain cereals, dried peas and beans, nuts	helps build bones, important in muscle contraction, regulation of body temperature	nervousness, sensitivity to noise, rapid heartbeat, possible convulsions
Calcium	milk products, green leafy vegetables, dried fruits	formation of bones and teeth, needed for blood clotting, needed for nerve and muscle function	poor bone and tooth structure, slow blood clotting, muscle spasms
Phosphorus	milk products, meats, fish, poultry, nuts, whole-wheat cereals	bone and teeth formation, nerve and muscle function, energy production	poor tooth and bone structure, muscle spasms
Iron	liver, meats, eggs, nuts, soybeans, dried fruits, green leafy vegetables	needed by red blood cells, involved in energy releasing process in cells	anemia, lack of energy
Sodium and Potassium	most foods	maintains tissue fluid balance, needed for nerve functioning	weakness, nervous disorders, cramps

for good health. However, supplemental vitamins can be purchased. They are usually recommended for babies and young children, for pregnant mothers, and for people who have special dietary problems.

CHECK YOUR FACTS

- 1. What are the six categories of human food needs? Which is most likely to be deficient?
- 2. What is nutrition? What is malnutrition?
- 3. What happens when the body is deficient of proteins? Why are diseases more likely to occur?
- 4. What is an essential amino acid? Where are they obtained?
- 5. What are complete proteins?

SCIENCE BACKGROUND

Any discussion of vitamins will create a controversy because dietary students and faddists usually have extremely strong opinions about the pros and cons of certain foods and vitamin supplements. The students should be advised that they will probably be bombarded with opinions and advertisements, many of which have not been endorsed by human nutrition experts or by the medical profession.

Table 33-3 Vitamins

<i>Vitamin</i>	<i>Good Sources</i>	<i>Functions</i>	<i>Effect of Deficiency</i>
A	green leafy vegetables, yellow vegetables and fruits, liver, carrots, tomatoes, butter	essential for good vision and normal growth, helps form teeth and bones, promotes healthy skin	poor vision, night-blindness, poor growth, digestive disorders, kidney problems
Folic acid	liver, yeast, green vegetables, beans and peas, whole-grain foods	essential for human growth and reproduction, formation of red blood cells	anemia, stunted growth
Thiamine B ₁	pork, liver, lamb, green vegetables, dried soybeans, nuts, oysters, brown rice	helps maintain good digestion, elimination, memory, helps release energy,	poor appetite and digestion, impaired nerve function, poor memory
Riboflavin B ₂	milk, liver, lean meat, green leafy vegetables, eggs, cheese	promotes growth, promotes healthy skin and hair, reproduction	stunted growth, skin and hair problems, poor vision
Niacin	peanut butter, liver, tuna fish, salmon, lean meat, dried peas and beans, cornmeal	promotes health of nervous and circulatory systems, helps release energy	emotional and nervous disorders, skin disorders
Pyridoxine B ₆	milk, wheat germ, liver, brown rice, corn, whole wheat cereal	general maintenance of health	rash, dizziness, nervous disorders, mental confusion, nausea
B ₁₂	liver, organ meats, eggs, milk, shellfish	formation of blood	anemia
C	citrus fruits, tomatoes, strawberries, peppers, potatoes, cantaloupe	helps hold cells and tissues together, tissue maintenance	poor healing, susceptibility to infection, hemorrhaging
D	liver, fish-liver oils, eggs	promotes strong bones and teeth	weak teeth and bones
E	wheat germ, oils, milk, eggs, liver, vegetables	uncertain, possibly a role in reproduction	unknown
K	cereals, meat, green leafy vegetables	blood clotting, digestion	hemorrhaging

SUMMARY

The digestive system breaks down food into the molecular form that can be absorbed into the bloodstream and used by the cells. Three processes are involved: mechanical digestion, chemical digestion, and absorption. In the mouth, food is chewed and mixed with saliva. Food enters the stomach through the cardia and exits through the pylorus. The stomach, like the rest of the digestive tube, is made up of smooth muscle tissue. The duodenum, jejunum, and ileum make up the small intestine. Most chemical digestion and absorption occur here. A well-balanced diet should include adequate amounts of all essential minerals and vitamins.

REVIEW QUESTIONS

1. Describe the mechanical digestion that occurs in the digestive system.
2. Where does chemical digestion take place?
3. Where are digestive juices and enzymes produced?
4. What structures are involved in the digestion of fat?
5. Describe the process of absorption.
6. Where are sphincters located?
7. Describe, in terms of the digestive tract, what happens when a person vomits. What is happening when a person chokes? What should be done to help a person who is choking?
8. What are the parts of a tooth? How are they held in place?
9. What are the enzymes that digest proteins? Carbohydrates? Fats?
10. A bite of food is about to be swallowed. Name the structures this food will pass by before some of it is eliminated as waste.

ANALYSIS AND APPLICATION

1. Why are carbohydrates much better foods for quick energy than fats?
2. What type of food would be hardest to digest for a person whose stomach has been removed? Why?
3. Canada currently ships tonnes of grain to developing nations to help feed starving people. Even if more grain could be grown, shipped, protected from rodents, and distributed to the people that need it most, why would the problem of malnutrition be far from solved? What would it take to solve this problem?

ANSWERS TO REVIEW QUESTIONS

1. The teeth break down the food into smaller pieces. Peristaltic waves continue to reduce the size of food particles.
2. In the mouth, stomach, and small intestine.
3. In the parotid glands, the stomach lining, the liver, the pancreas, and the microvilli.
4. Teeth, liver, gallbladder, pancreas, small intestine, and microvilli.
5. See section 33–15.
6. Near the base of the esophagus, at the pylorus, at the end of the small intestine, and at the anus.
7. Food is forcefully ejected from the stomach, forcing the sphincter to open and allowing the food to travel up the esophagus, through the pharynx, and out of the mouth. Choking is caused by the entry of food into the trachea. The Heimlich hug should be administered.
8. See section 33–3.
9. Proteins are digested by pepsin and proteases. Carbohydrates are digested by salivary amylase, pancreatic amylase, and enzymes from the microvilli. Fats are digested by pancreatic lipase and lipases from the microvilli.
10. The list should include the major structures of the digestive system.

ANSWERS TO ANALYSIS AND APPLICATION

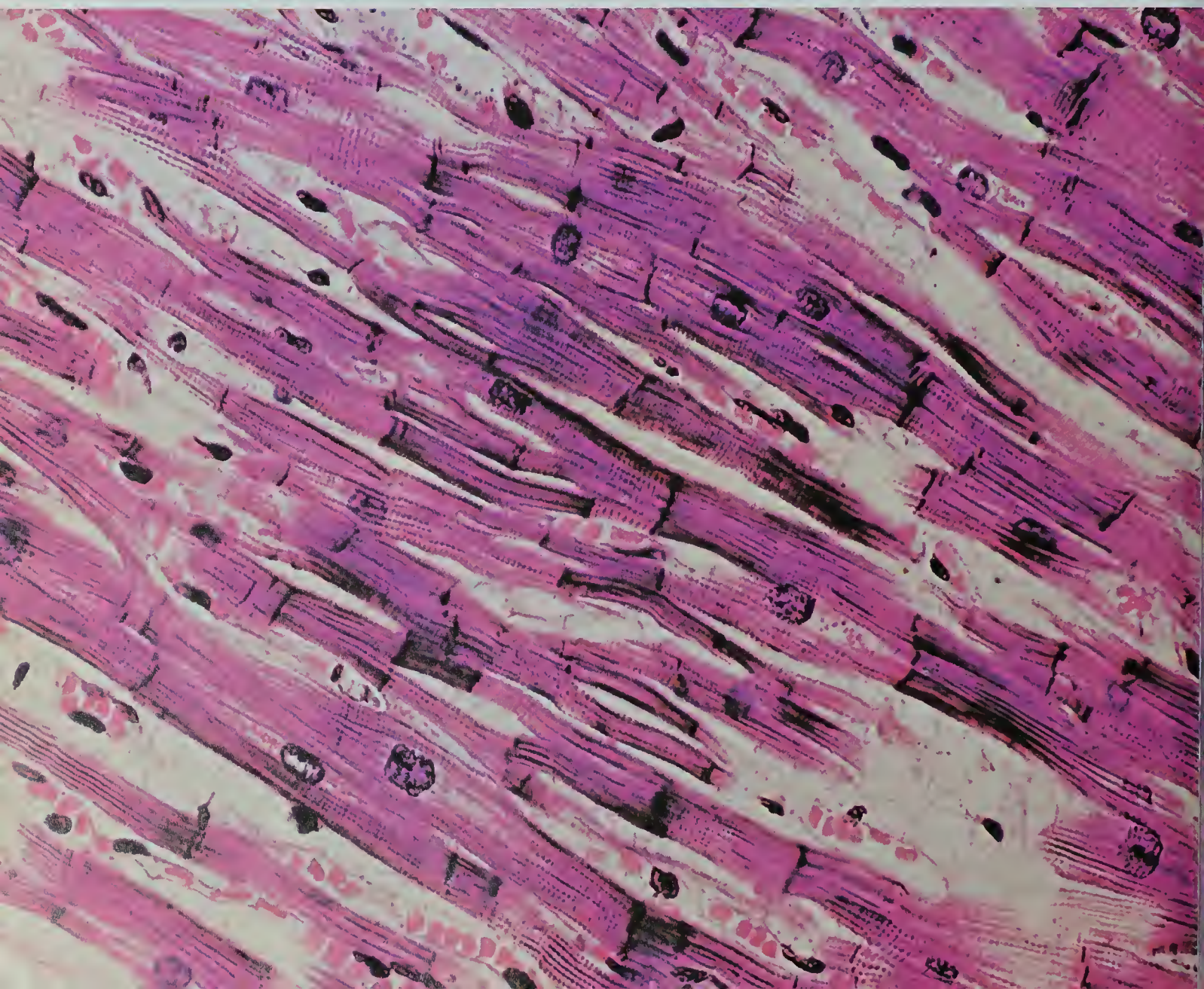
1. Carbohydrates are digested more easily and they are absorbed quickly.
2. Proteins, because pepsin has been eliminated.
3. Grains do not supply all the essential amino acids that are probably lacking in the diet of these people. They would need additional protein.

Investigations 51–53 from *Laboratory Investigations in Biology* can be done with this chapter.

OBJECTIVES

- To list the five basic functions of blood in the human body
- To explain the nature and unique function of erythrocytes, leukocytes, and platelets

34 *Blood and*



- To understand the structure of the four-chambered human heart and how the blood moves within it
- To discuss the unique nature of cardiac muscle
- To understand the basic structure and function of arteries, veins, and capillaries
- To know the general pathway in the systemic circulation
- To explain the basic pathway of the pulmonary circulation
- To understand the nature of muscle sphincters in the arterioles
- To understand the problems associated with arteries that become clogged with fatty material or lose their elasticity
- To appreciate the role of the lymphatic system and the lymph nodes in defending the body from infectious invaders

Circulation

Blood

34-1 Functions of the blood Every person has an average of 4.5 to 5 L of blood in their body. This is usually about 8 percent of a person's body weight. Blood performs six important functions:

1. Carries food to all the cells;
2. Carries oxygen to all the cells;
3. Carries wastes away from the cells, mainly to the lungs and kidneys;
4. Helps regulate body heat;
5. Carries hormones throughout the body;
6. Fights infectious disease agents, such as bacteria and viruses.

34-2 Composition of the blood There are two main parts of the blood. The liquid part is called **plasma** (plaz'mə). Plasma is yellow-brown in color and makes up about 55 percent of the blood. Plasma contains water (90 percent), dissolved nutrients, wastes, and specific blood proteins.

The other 45 percent of the blood is made up of **formed elements**. These include red blood cells, white blood cells, and platelets.

34-3 Red blood cells The red blood cells, or **erythrocytes** (i rith'rō sīts), are circular and biconcave in shape. They are very small cells—smaller than most other cells in plants and animals. The mature erythrocytes do not have a nucleus. Nor do they have mitochondria,



When blood is centrifuged, the formed elements clump together at the bottom of the tube and the plasma collects at the top.

SCIENCE BACKGROUND

The erythrocytes are about $7.5\mu\text{m}$ in diameter. Someone estimated that the average erythrocyte travels about 1127 km during its lifetime. The erythrocytes are produced by erythroblasts, which are nucleated, normal cells. Their source changes from the time of fetal development up through adulthood. Before the age of 20 many are produced in the red marrow in the ends of the long bones and in the bones mentioned in the text. Two B vitamins, B_{12} and folic acid, are necessary for erythrocyte production.

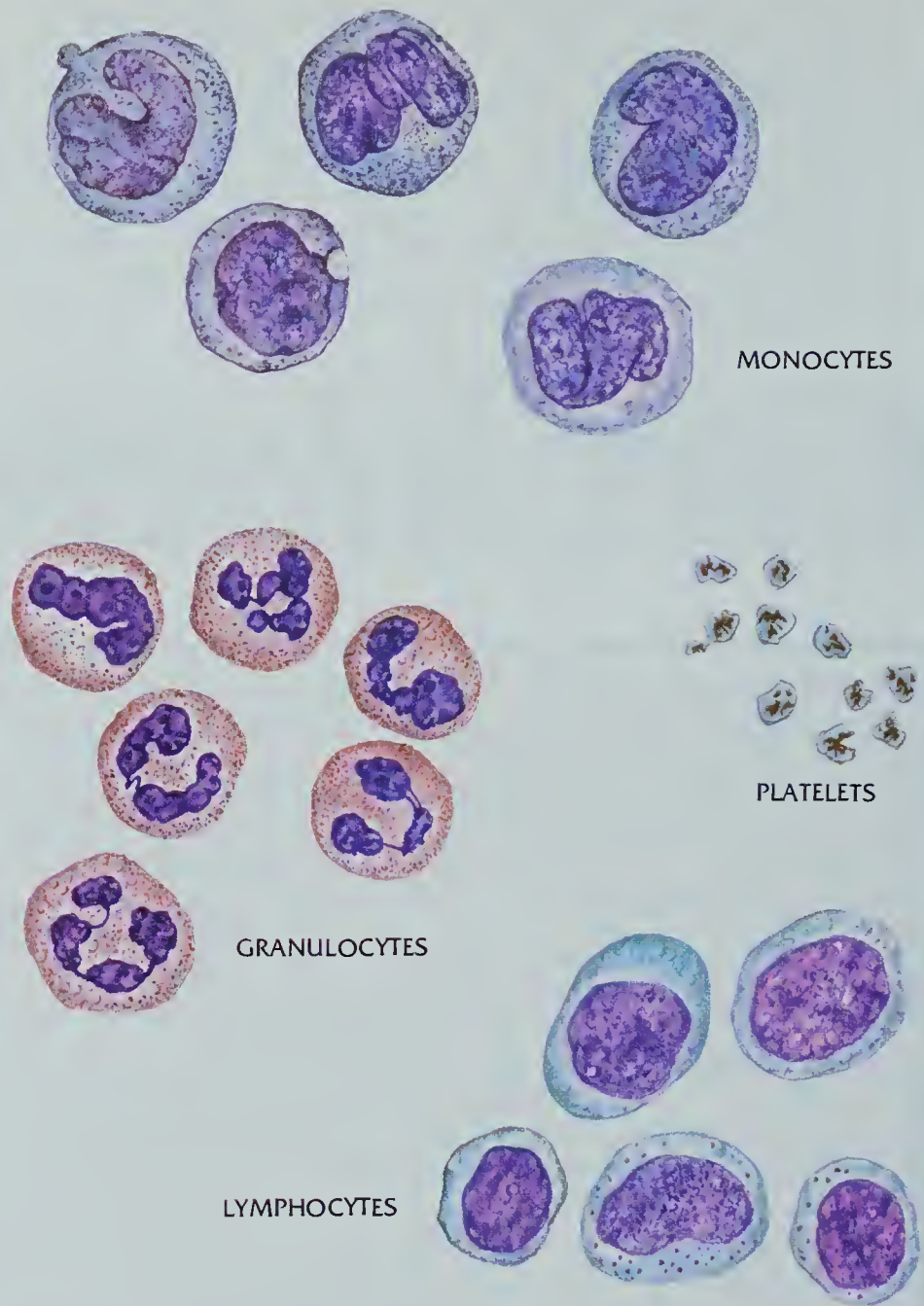


FIGURE 34-1

The three different types of leukocytes are illustrated in this figure. The much smaller platelets are also shown.

RNA, centrioles, or a Golgi apparatus in their cytoplasm. For this reason they are sometimes called corpuscles rather than cells.

The erythrocytes carry oxygen to the cells of the body. The oxygen is picked up in the lungs, where it bonds to hemoglobin in the erythrocyte. The oxygen forms a loose bond with the iron that is in hemoglobin. Later the oxygen breaks away from the hemoglobin and diffuses into other cells. The oxygen is used during aerobic respiration. This

is the process by which energy is released in the mitochondria.

Erythrocytes are produced in the **red bone marrow** (mar'ō), which is in the core of bones, such as the ribs, sternum (breastbone), vertebrae, and pelvic bones. Once the erythrocytes are in the circulation, they live for about 120 days. After that time they become brittle. Many break up, especially as they flow through an abdominal organ called the **spleen** (splēn).

34-4 White blood cells The white blood cells, or **leukocytes** (lü'kə sīts), are much larger than the erythrocytes. They have a nucleus and all the organelles found in a normal cell. The leukocytes have one major function and that is to protect you from foreign invaders, such as bacteria and viruses.

There are three basic types of leukocytes. One type, called the **granulocyte** (gran'yə lə sīt), has a lobed nucleus and large granules in the cytoplasm. The granulocytes make up from 65 to 75 percent of the leukocytes. Most of the granulocytes are phagocytes, which are "eating cells." If bacteria enter the body through a break in the skin, the granulocytes are attracted to the injury. There they eat, or phagocytize, anywhere from 5 to 25 bacteria before they die.

A second type of leukocyte has two different names. While it is circulating in the blood, it is called a **monocyte**

MAIN IDEA

Leukocytes protect the body from disease agents. Granulocytes, monocytes or macrophages, and lymphocytes are all leukocytes.

SCIENCE BACKGROUND

There are three kinds of granulocytes: neutrophils, eosinophils, and basophils. The eosinophils multiply during certain infections and during allergic reactions. They are thought to detoxify certain toxins produced by bacteria. The basophils may produce the heparin, which flows in the bloodstream and normally prevents blood clot formation in the bloodstream.

The granulocytes and the monocytes (macrophages) are capable of amoeboid movement, and they escape from blood vessels by squeezing, a little at a time, either between the cells of capillaries or through tiny pores in small vessels. Their process of escaping is called diapedesis.

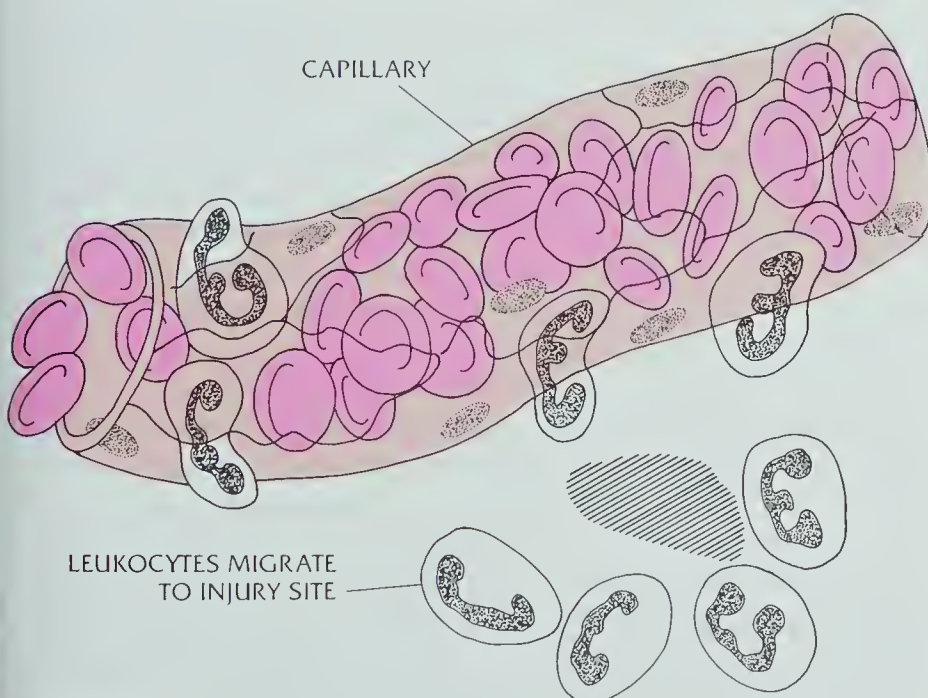
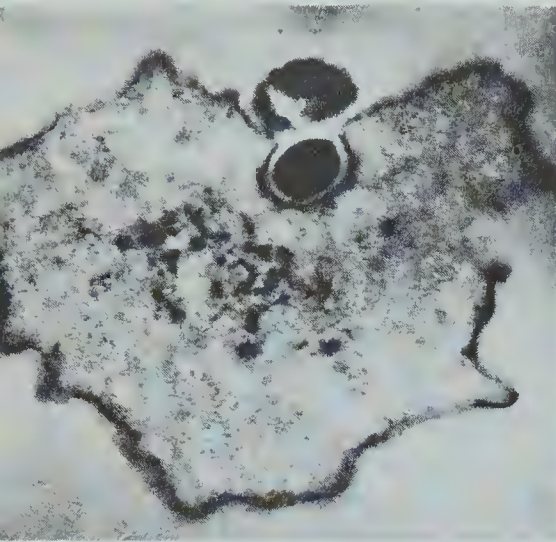


FIGURE 34-2

Leukocytes may leave the blood vessels by squeezing through the walls of capillaries to attack bacteria in other tissues.



A large macrophage can be seen in the process of engulfing a bacterium in this photograph.

MAIN IDEA

The blood clotting mechanism in the body usually prevents the excessive loss of blood from injured tissue. Such clotting can be dangerous in the bloodstream.

SCIENCE BACKGROUND

The platelets are cytoplasmic fragments of megakaryocytes.

SCIENCE TERMS

plasma
formed elements
erythrocytes
red bone marrow
spleen
leukocytes
granulocyte
monocyte
macrophage
lymphocyte
globulins
platelets
fibrinogen
fibrin

(mon'ə sīt). However, it is also a phagocyte, and many leave the bloodstream to eat bacteria in other tissues. When outside the bloodstream, it is called a **macrophage** (mak'rə faj), which means "big eater." And that is a good name. Macrophages can eat up to 100 bacteria before they die. This is five times more than the granulocyte can eat. Both the macrophage and granulocyte also clean up the tissues. They eat dead leukocytes, broken cell fragments, blood clots, and dead tissue.

The third type of leukocyte is called a **lymphocyte** (lim'fə sīt). Lymphocytes help fight disease organisms by an entirely different method. They help convert some of the plasma proteins, or **globulins** (glob'yə lins), into antibodies. The antibodies then destroy the invaders.

34-5 Platelets The **platelets** (plāt'lits) are very small noncellular bodies. The platelets have two functions. They plug leaks in small blood vessels until the injured tissue has healed. They also function in the blood clotting process.

34-6 Blood clotting Anytime there is an injury, there is a risk that too much blood will be lost and the victim will die. Fortunately that risk is small for most injuries. The blood has its own self-sealing mechanism, called the blood clotting mechanism. It usually prevents a dangerous loss of blood.

At the site of an injury, platelets scrape against the rough edges of the broken tissue and release a substance that triggers the clotting mechanism. This mechanism converts one of the plasma proteins, **fibrinogen** (fī brin'ə jen), into another protein form. This new protein, called **fibrin** (fī'brən), is insoluble and forms tough threads. The fibrin threads form a criss-cross pattern over the injury, trapping the red blood cells and forming a clot. Then slowly the clot contracts, pulling the edges of the wound together and sealing off the blood flow.

The blood clotting mechanism is very useful, but it can also be very dangerous. If a clot should form inside a blood vessel, it could be washed along until it plugs up a small blood vessel. If that plugged vessel happens to be in the brain or heart, serious problems or death can result. The brain and heart are tissues that demand a constant supply of oxygen. Without oxygen, brain and heart tissues die quickly. Such tissue death can cause a stroke (brain) or a heart attack. Fortunately we have mechanisms in our body that normally prevent the formation of clots in our bloodstream.

CHECK YOUR FACTS

1. How much blood is in the human body?
2. What are the six functions of blood?
3. What is plasma? What does it contain?
4. What are the formed elements? Which is noncellular?
5. Why are erythrocytes sometimes called corpuscles, instead of cells?
6. How is oxygen carried by erythrocytes?
7. Where are red blood cells produced? How are they destroyed?

Heart and Blood Vessels

34-7 Structure of the heart The human heart lies just behind the sternum (breastbone). It is slanted, with the tip on the left side. The average heart is about 13 cm long and 9 cm wide, or about the size of a person's fist. It is enclosed in a saclike membrane called the **pericardium** (per ə kăr'dē əm).

The heart has four cavities, or chambers: two atria on top and two ventricles below. However, there is no connection between the right and the left sides of the heart. Therefore it is common to think of two separate hearts, the right heart and the left heart.

The right heart receives blood from the body. This is blood that has been to the tissues and is low in oxygen and high in carbon dioxide. The blood enters the right atrium, then flows through the **tricuspid** (trī kus'pid) **valve** into the right ventricle. Then the ventricle contracts, forcing the blood out through an artery to the lungs. This puts pressure on the tricuspid valve and forces it shut. The flaps of the valve are prevented from collapsing into the atrium by strong cords that are attached to them.

The left atrium receives blood from the lungs. This blood flows through the **bicuspid** (bī kus'pid) **valve** (also called the **mitral** (mī'trəl) **valve**) into the left ventricle. The left ventricle contracts and pumps blood out through an artery to the body. The bicuspid valve also has cords attached to it that keep it from collapsing.

34-8 Cardiac muscle The walls of the heart are made up of a unique type of muscle tissue called **cardiac** (kăr'dē ak) **muscle tissue**. This muscle tissue is made up of bundles of fibers that branch and rebranch, so that they are connected to each other. This causes nerve impulses to spread over the whole mass of tissue, causing it to contract

ANSWERS TO CHECK YOUR FACTS

1. About 4.5 to 5 liters.
2. It carries (1) food, (2) oxygen, (3) wastes, (4) hormones. (5) It regulates body heat. (6) It fights infectious agents of disease.
3. The liquid part of blood. It contains water, dissolved nutrients, wastes, and blood proteins.
4. Erythrocytes, leukocytes, and platelets. Platelets.
5. They lack a nucleus, a Golgi apparatus, mitochondria, RNA, and centrioles.
6. It is loosely bonded to the iron of the hemoglobin molecule found in erythrocytes.
7. In the red bone marrow. They become brittle after about 120 days and break up. The spleen contributes to this process.

MAIN IDEA

The four-chambered heart receives blood from the body in the right atrium and pumps it to the lungs by contracting the right ventricle. The left side of the heart pumps blood from the lungs to the body.

SCIENCE BACKGROUND

Some references continue to use *auricle* rather than *atrium* to describe the heart's upper chambers. Students should probably be aware of both terms. The term *auricle* in Latin means "little ear."

MAIN IDEA

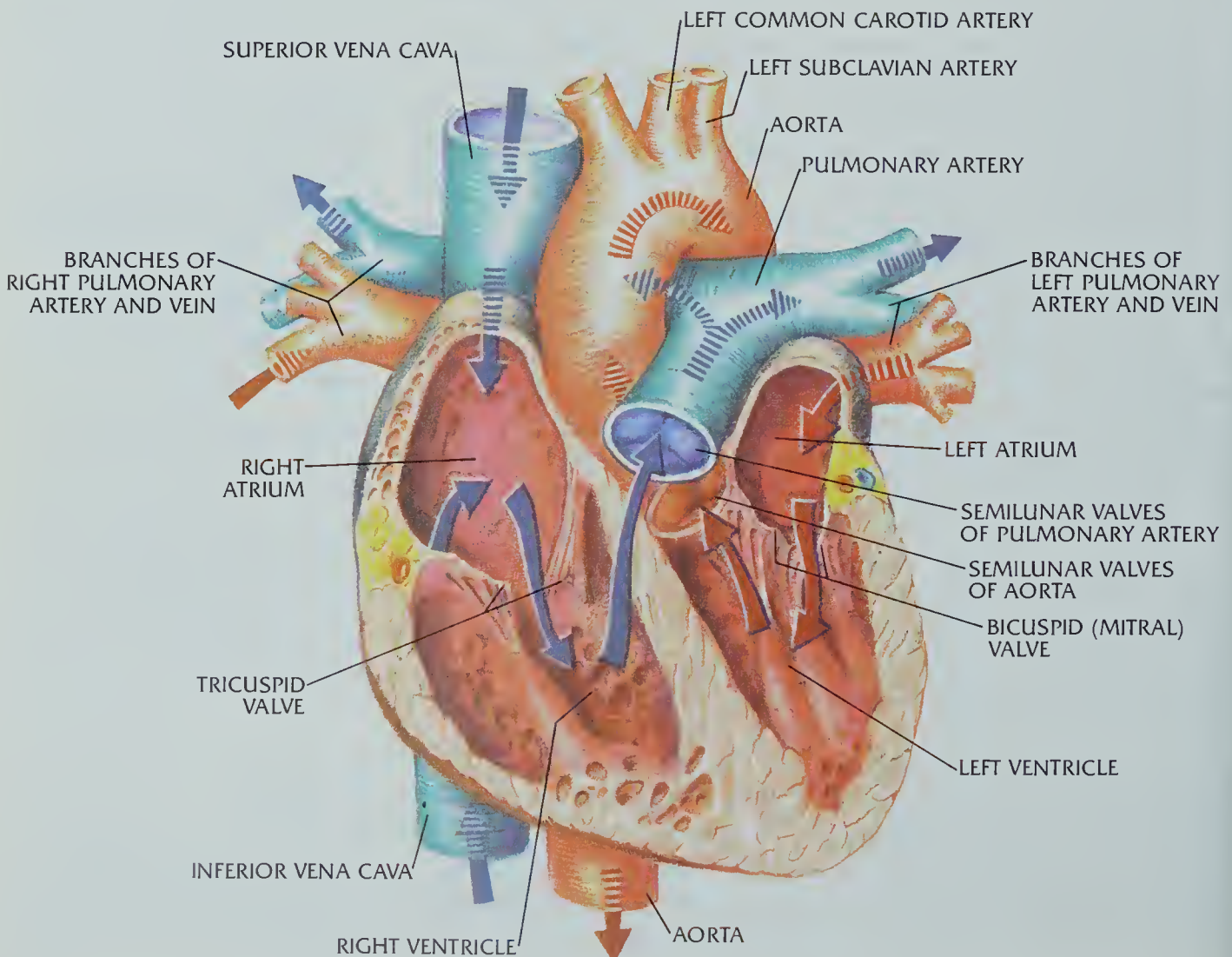
Cardiac muscle is aerobic muscle that never tires but is completely dependent upon a continuous supply of oxygen.

uniformly. Cardiac muscle tissue is involuntary, which means that it is not under our conscious control. Cardiac muscle has one unique characteristic. It is strictly an aerobic muscle. This means that it can only obtain energy by aerobic respiration.

Other muscle tissues—smooth muscle that moves our internal organs and skeletal muscle that moves our body—can obtain energy by two methods. By anaerobic respiration they can obtain two molecules of ATP by breaking a glucose molecule into lactic acid. This is done without the presence of oxygen. However, there is a problem because lactic acid is a muscle poison. As it builds up it causes the muscles to become tired, and enough lactic acid will cause them to stop working altogether. Eventually, of course, the problem is solved because oxygen reaches the muscles and is used in aerobic respiration. This breaks down the lactic acid and eliminates the tiredness. Then the muscles are ready to work again.

FIGURE 34-3

A cutaway of the human heart and the major blood vessels associated with it is illustrated in this figure.



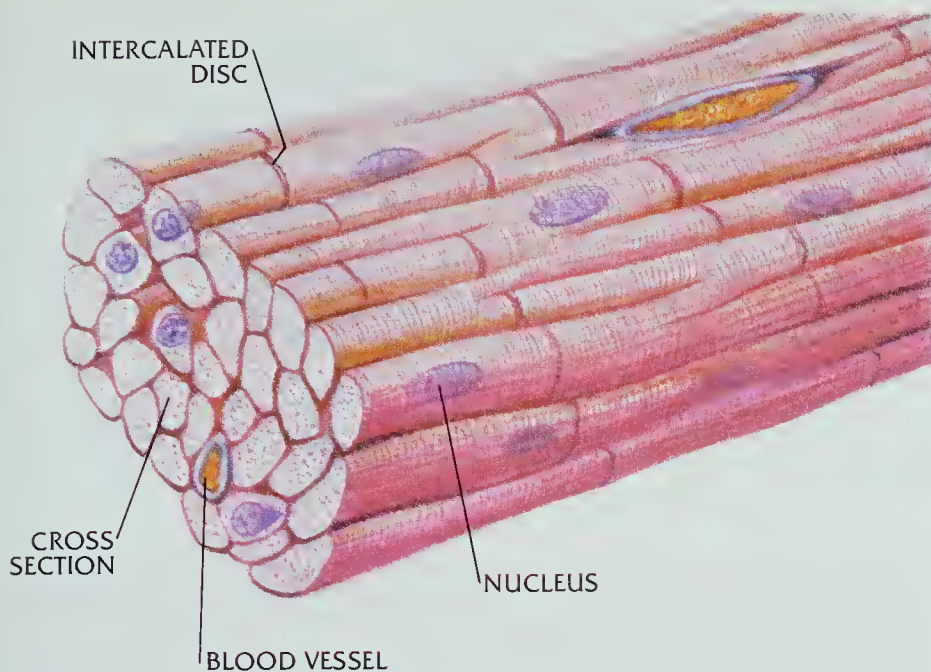


FIGURE 34-4

Cardiac muscle tissue, found only in the heart, is involuntary and strictly aerobic.

SCIENCE TERMS

pericardium
tricuspid valve
bicuspid valve
cardiac muscle tissue
pulse
arterioles
venules

What would happen if cardiac muscle could obtain energy by anaerobic respiration? After heavy work the cardiac muscle would become tired and could quit working. Of course, that would be a disaster—it would cause death. So it is good that cardiac muscle cannot obtain energy by anaerobic respiration.

But there is another possible danger. Using aerobic respiration the cardiac muscle is completely dependent upon oxygen always being present. If something happens to cut off the oxygen supply, such as an artery getting plugged with a blood clot, the tissue will die. This death occurs immediately, and if enough tissue dies, the heart will stop beating. So the good news is that the heart muscle will never stop working because it is tired. The bad news is that anything that shuts off its oxygen supply will cause it to die.

34-9 The blood vessels There are three kinds of blood vessels in the circulatory system: arteries, capillaries, and veins. At any given time, 15 to 20 percent of the blood is in the arteries and another 5 percent is in the capillaries. Besides what little is in the heart, the major portion of the blood—about 75 percent—is in the veins.

34-10 Arteries The arteries have a definition based on their function. The arteries are the blood vessels that carry blood away from the heart. But the arteries also have a unique structure. Their walls are thick and are made up of smooth muscle, elastic tissue, and strong connective tis-

SCIENCE BACKGROUND

Artery is the Greek word for “air duct.” Supposedly early anatomists always found the arteries empty and thought they were tubes for carrying air.

Injury to an artery is much more dangerous than damage to the other vessels. The blood flows in spurts, and the bleeding is much more difficult to stop. However, the arteries are buried more deeply in the body and are less likely to be damaged than the veins.

MAIN IDEA

Arteries, capillaries, and veins are the three kinds of blood vessels. Most blood is present in the veins.

MAIN IDEA

Arteries are elastic, thick-walled vessels that carry blood from the heart.

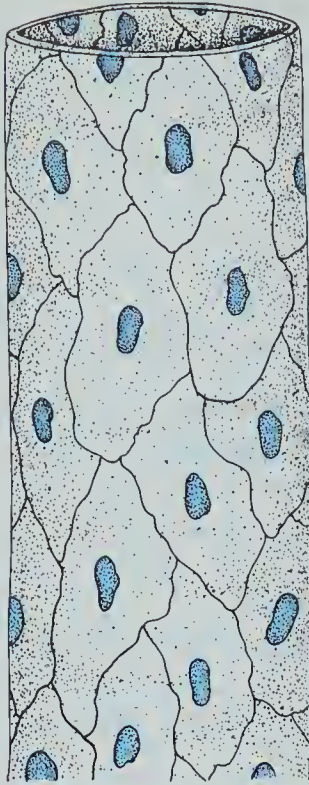


FIGURE 34-6
The walls of capillaries are only one-cell thick. It is through the capillaries that materials are exchanged.

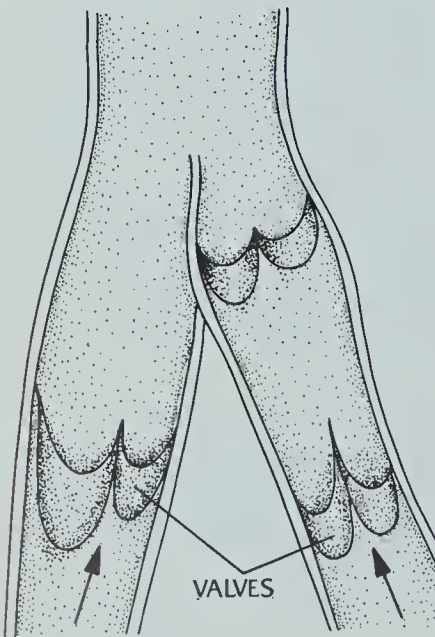


FIGURE 34-7
Blood moves more slowly in veins than in arteries. It is prevented from backing up by the presence of numerous one-way valves.

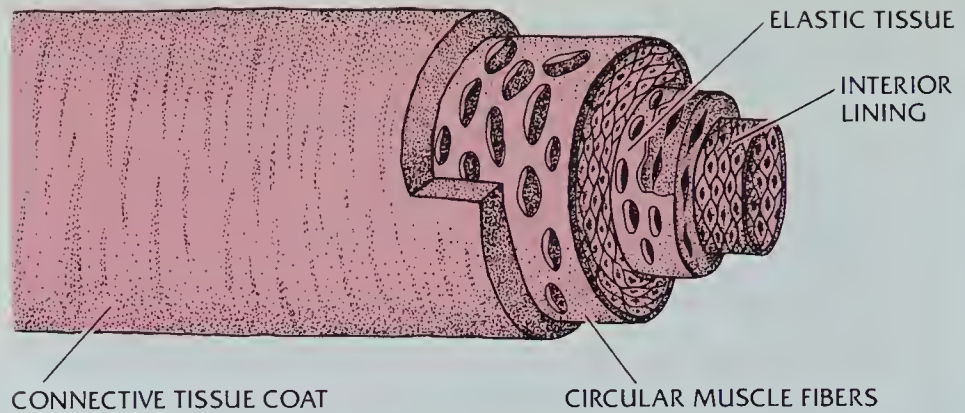


FIGURE 34-5 The structure of an artery is illustrated above. Arteries have more muscle tissue and elastic tissues than veins do.

sue. The elastic tissue allows them to stretch when there is a surge of blood pressure as the heart contracts. This stretching of the arteries as the heart contracts, or beats, can be felt and is called the **pulse** (puls). After the main arteries leave the heart, they branch and rebranch into smaller arteries that are called **arterioles** (är tir'ē olz). Arterioles have thinner walls and are less elastic than the larger arteries.

34-11 Capillaries Eventually the arterioles branch into extremely small vessels called capillaries. The capillaries are only about 0.01 mm in diameter and 0.5 to 1 mm long. The wall of the capillary is very thin and made up of flat cells that are rolled into a tube shape. Blood plasma leaks from the capillaries through pores between the cells in the capillary wall. Some substances diffuse directly through the cells in the capillary wall. The plasma then becomes tissue fluid, which bathes the cells of all the tissues, provides them with food, and carries their wastes.

34-12 Veins Blood flows from the capillaries to small veins called **venules** (ven'yulz). The venules come together and eventually form veins, which are defined as vessels that carry blood toward the heart. The veins have much thinner walls than arteries. Veins have much less muscle and elastic tissue. The pressure that forces blood through the arteries does not continue on through the capillaries and into the veins. Therefore they do not have to be as strong as the arteries. Blood moves slowly and more evenly in the veins than in the arteries. It is moved, most of the time against gravity, by the squeezing action of muscles. Assisting with this movement are the many one-way valves that are in the veins.

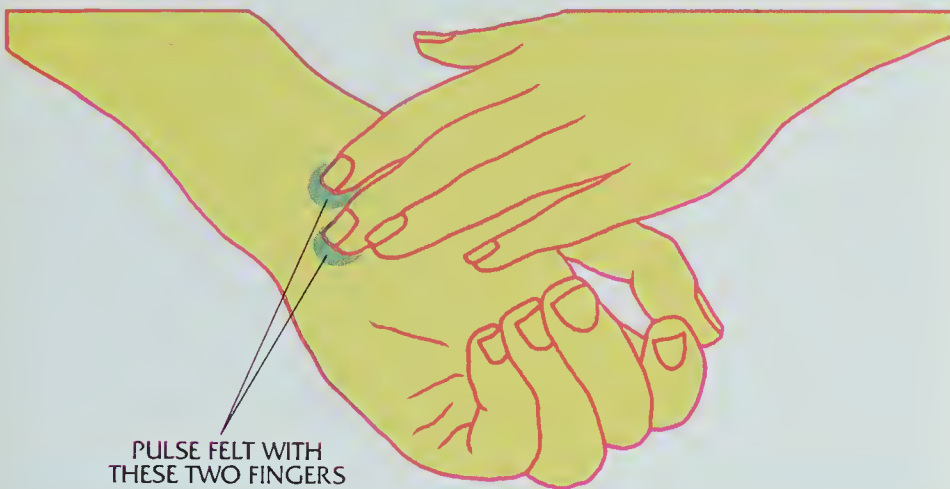


FIGURE 34-8

Although the pulse is normally taken at the wrist, there are many other locations on the body where the pulse can be detected.

CHECK YOUR FACTS

1. What is the pericardium?
2. Where in the heart are there openings between chambers?
3. What structures are found at the openings mentioned above?
4. Describe cardiac muscle tissue.
5. Where is most of the blood in the body?
6. Describe arteries and arterioles. What is their function?

ANSWERS TO CHECK YOUR FACTS

1. The saclike membrane that encloses the heart.
2. Between the atrium and the ventricle of the left side and of the right side.
3. In the left heart, the bicuspid valve. In the right heart, the tricuspid valve.
4. It is composed of bundles of fibers that are all interconnected, causing nerve impulses to spread uniformly over the entire tissue. It is involuntary and aerobic.
5. In the veins; most of the remaining blood is in the arteries.
6. Arteries have thick walls that are made of smooth muscle tissue, elastic tissue, and strong connective tissue. Arterioles are smaller, have thinner walls, and have less elastic tissue. They both carry blood away from the heart.

Circulatory Patterns

34-13 The systemic circulation There are two main circulatory patterns for blood in the body. One is the **systemic** (sis tem'ik) **circulation**, which carries blood from the heart to all parts of the body and back to the heart.

We can begin a description of the systemic circulation in the left heart. Bright red blood, rich in oxygen, arrives in the left atrium from the lungs. Such blood is often called **arterial** (är tir'ē əl) **blood**. When the left atrium is full, the walls contract in a process called **systole** (sis'tə lē). Systole forces open the bicuspid valve between the left atrium and the left ventricle, and blood fills the ventricle. Then the atrium relaxes and expands back to normal size, a process called **diastole** (dī as'tə lē). (Think of squeezing a small hollow rubber ball that has a hole in it. When you release the ball, air rushes in and fills it, causing it to take its original shape. That is a process like diastole.) The pressure of the blood slams the bicuspid valve shut, which is a noisy event like a door slamming. At the same time the blood forces open the valve between the left ventricle and the largest artery in the body, the **aorta** (ā ôr'tə). The

MAIN IDEA

In systemic circulation, systole in the left atrium opens the bicuspid valve and forces blood into the left ventricle. Diastole here shuts the bicuspid and opens the semilunar valve, and blood passes into the aorta.

SCIENCE BACKGROUND

The blood returns to the heart via four separate pulmonary arteries. These will be mentioned during the discussion of the pulmonary circulation.

valve between the left ventricle and the aorta is called a **semilunar** (sem ē lū'nər) **valve**. Then diastole occurs in the left ventricle, and backward pressure in the aorta slams the semilunar valve shut.

MAIN IDEA

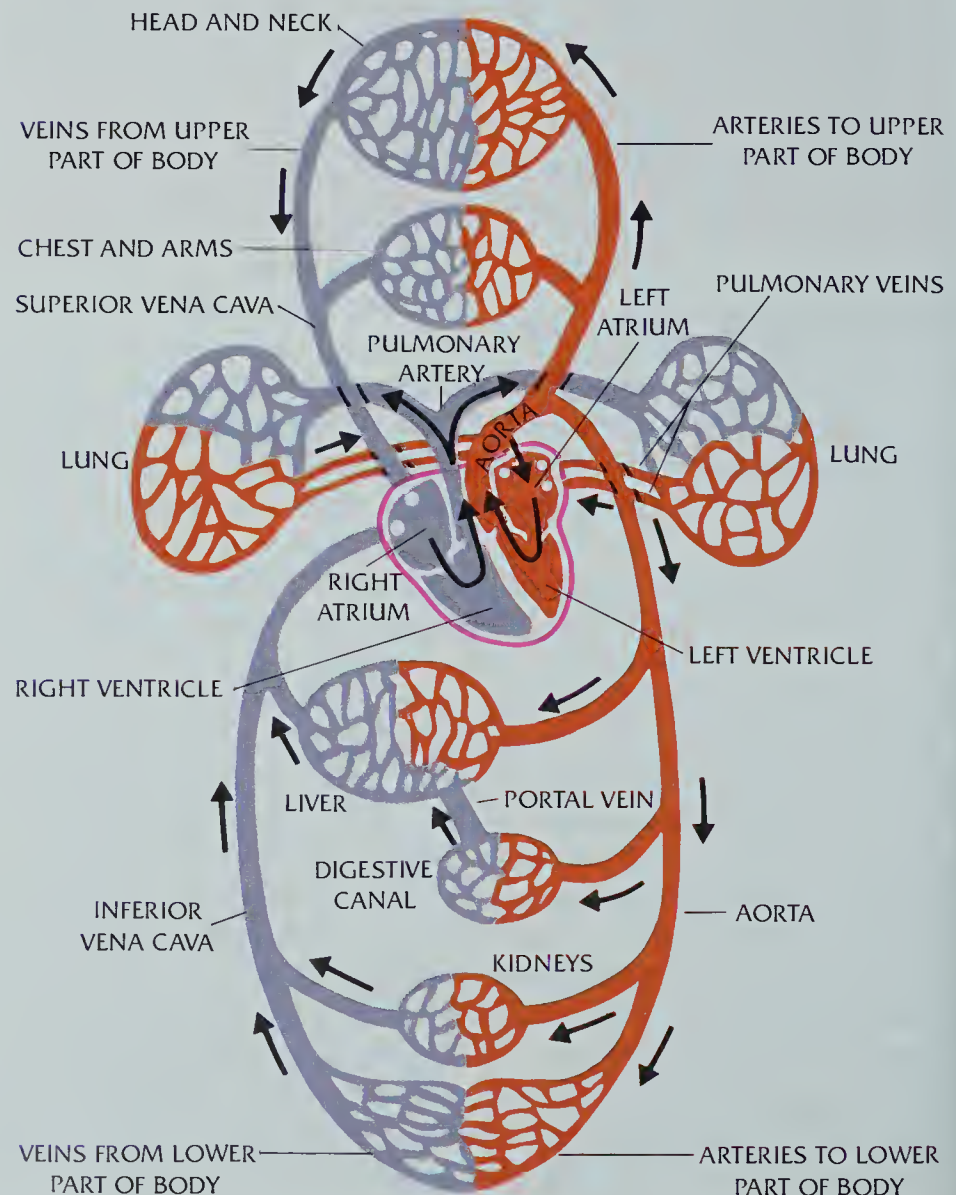
The beat of a heart is actually the sound of the bicuspid, tricuspid, and semilunar valves being forcefully shut.

SCIENCE BACKGROUND

Doctors always listen for heart sounds other than the lub-dub described in the text. The sound of flowing blood or a heart murmur indicate that the valves are not closing completely. Stenosis, which is a buildup of scar tissue that will not allow the valves to open completely, can be heard as rushing blood between the lub-dub.

34-14 The heart sounds This is a good time in the discussion to explain the heart sounds. By listening to the chest region with an instrument called a **stethoscope** (steth'ə skōp), one can hear a series of heart sounds. They are often described as: lub-dub, lub-dub, lub-dub. These sounds are caused mainly by the valves slamming shut. The first sound, "lub," occurs when the ventricles contract and slam the bicuspid and tricuspid (right heart)

FIGURE 34-9 The path of blood around the body is illustrated, in a general way, in the figure below.





SCIENCE BACKGROUND

The three arteries that branch off the aorta after the coronaries are the brachiocephalic, left common carotid, and left subclavian. However, there is considerable individual variation, with sometimes one, two, or four branches.

The sounds made by the heart can be detected with a stethoscope. These sounds can aid a doctor in diagnosing possible disorders.

valves shut. The second sound, “dub,” occurs during diastole of the ventricles when back pressure slams the semilunar valves shut.

34–15 The systemic pathway The first segment of the aorta rises above the heart. The first arteries to branch off the aorta are the two **coronary arteries**. These carry arterial blood to all parts of the heart.

A short distance above the heart the aorta forms an arch and then descends down the back of the abdomen, running near the spine. At the arch, three large arteries branch off and take blood to the arms and head. Farther down the aorta other arteries branch off to the lungs, digestive organs, and kidneys. Near the bottom of the abdomen the aorta splits, with one branch going down the inside of each leg.

The arteries branch and rebranch into arterioles, then into capillaries. The blood then flows into venules, then veins, and finally into two main veins that carry the **venous** (vē'nəs) **blood** back to the heart. The main vein

MAIN IDEA

After leaving the heart, the aorta sends branches to the upper body, then follows the spinal cord to send branches into the lower body. Venous blood from above the heart travels in the superior vena cava; the remaining venous blood, in the inferior vena cava.

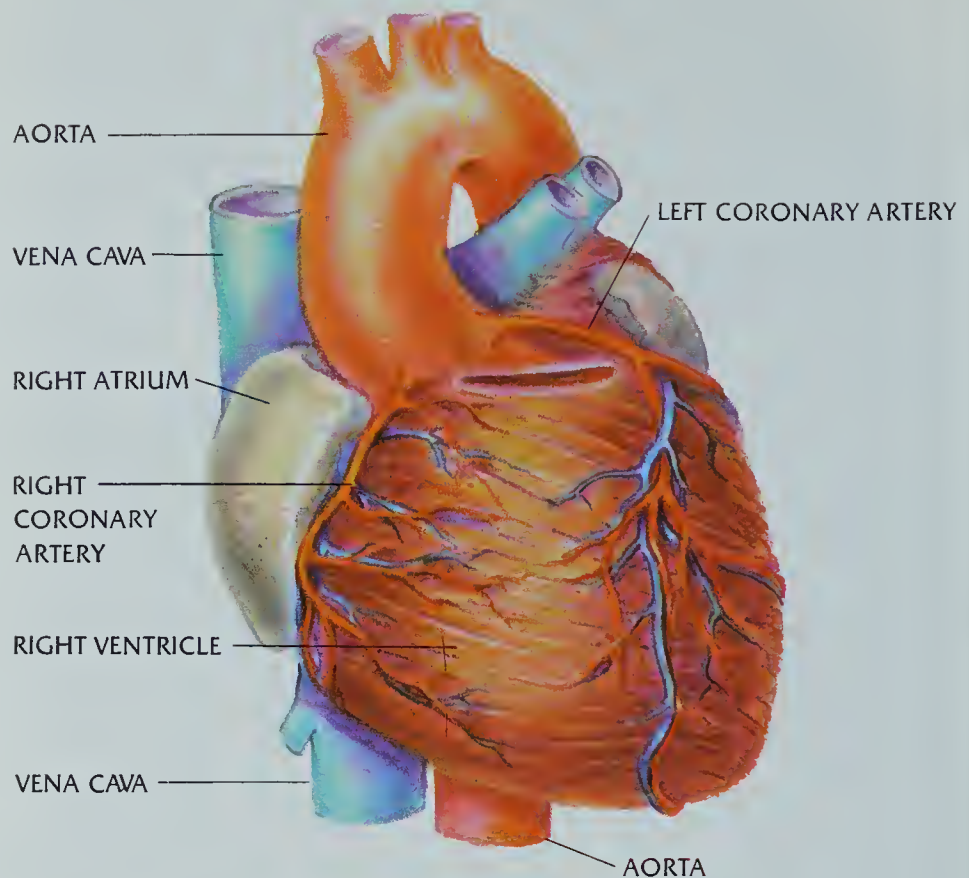


FIGURE 34-10

The coronary arteries, which branch from the aorta, supply blood to the heart muscle.

carrying blood from areas above the heart is the **superior vena cava** (vē'na kā'və). The vein carrying blood from the chest and lower body is the **inferior vena cava**. Both of these veins empty into the right atrium through separate openings.

MAIN IDEA

The right heart sends blood through the pulmonary artery to the lungs. Oxygen-rich blood returns to the left atrium in four pulmonary veins.

34-16 The pulmonary circulation The right atrium fills with venous blood during this chamber's diastole. In systole the venous blood is forced through the tricuspid valve into the right ventricle. Next, systole in the right ventricle slams the tricuspid valve closed. The venous blood is forced through a semilunar valve into the **pulmonary** (pul'mə ner ē) **artery**, which splits and carries blood to each lung.

In the lung the arteries branch into arterioles, then into capillaries where gas exchange occurs. The blood, now rich in oxygen, collects into venules and finally into two pulmonary veins from each lung. All four **pulmonary veins** empty into the left atrium. This completes the pulmonary circulation. When the left atrium fills and contracts, the blood starts on the systemic route again.

34–17 Shifts in the blood circulation Your body does not contain enough blood to support all possible body needs at the same time. For example, after eating a large meal, a large supply of blood is needed to serve the digestive organs. Much of the blood from arm and leg muscles is shifted to the digestive organs. However, should an individual start exercising, the majority of the blood would be shifted back to the leg and arm muscles. In this case there would not be enough blood for the digestive organs to function properly. The body would probably respond with pains of indigestion.

What causes the blood to shift from one part of the body to another? The arterioles are mainly responsible. The arterioles have muscular sphincters that can constrict (get smaller) or dilate (get larger). The constriction or dilation is caused by chemicals in the blood, or by nerve impulses.

The skin experiences the greatest variations in blood flow. Below the skin there are many small blood vessels, including a thick network of small veins. By constricting and dilating, these vessels control loss of body heat.

For example, during exercise, when a large amount of heat is produced in the body, the skin vessels dilate. A greater volume of blood then flows near the skin where the heat can be lost. At the same time, our skin is redder in color. The opposite occurs when we need to conserve the heat in our body. The vessels in the skin constrict. This keeps the blood away from the skin. Our skin looks whiter and may even take on a blue cast when the vessels are most constricted.

Emotions can also affect the vessels of the skin. Some persons turn “red with embarrassment” and “white with fear or anger” because of dilation or constriction of skin vessels.

34–18 Disorders of blood circulation There are many disorders that can affect the circulation of blood and our health. We shall discuss three that are very common.

One type of disorder is called **arteriosclerosis** (är tir ē ō sklə rō'sis), which means “hardening of the arteries.” Arteriosclerosis occurs as calcium deposits build up in the walls of the arteries, causing the arteries to lose their elasticity. Arteries need to be elastic to relieve some of the pressure of the blood being forced from the heart during systole. When the arteries lose their elasticity, the heart must work harder to force the blood through the body. As the pressure of the blood increases there is the danger that a small artery will rupture. If this occurs in the brain, the

MAIN IDEA

Muscular sphincters in the arterioles are responsible for shifting blood to the body area where it is temporarily needed in large amounts.

SCIENCE BACKGROUND

After the skin temperature reaches below about 15°C, a reflex action reverses the action and the vessels again dilate, sending more blood into the skin. However, this action, which gives the skin the cherry red look, helps to protect it from freezing.

An extreme blood shift occurs when a person goes into certain kinds of shock. Blood flows into the tissues, the arterioles dilate, and blood is drained from the head, lowering the blood pressure. The loss of blood in the brain causes fainting, and extreme shock can cause death.

MAIN IDEA

Arteries can lose their elasticity or become clogged with fatty material, causing increased blood pressure and the possibility of a stroke. A weak spot in an artery can lead to severe internal bleeding.

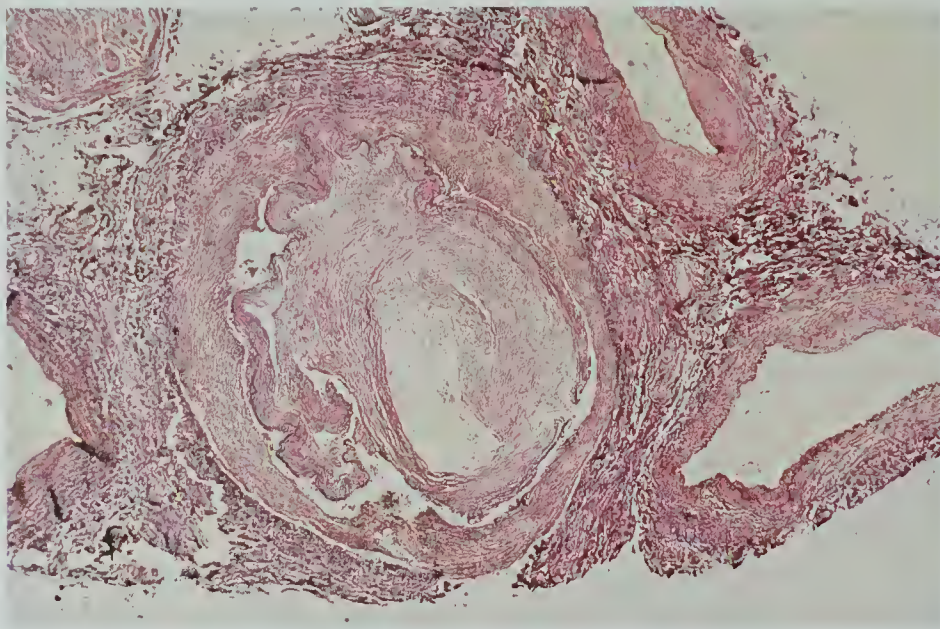
Fatty material deposited in the walls has narrowed the passageway of this artery. This increases the possibility of clot formation.

SCIENCE BACKGROUND

The term *stroke* describes the sudden impact created by the disorder—as if one were stroked with a club.

Atherosclerosis means, in Greek, "porridgelike hardening." Apparently early anatomists thought the buildup in the arteries looked like the globs of fatty material found in soups of that day. Generally four factors are implicated in atherosclerosis, all of which are unique to our modern culture: (1) lack of exercise, (2) overeating, particularly of high-cholesterol foods, (3) stress without physical release (such as being caught in a traffic jam when needing to be someplace else), and (4) smoking.

Various new surgical procedures enable persons to have sections of plugged up arteries removed and replaced with veins from the leg. The American Heart Association is a good resource agency for visual aids and speakers who can go into detail about new developments in the relief of circulatory disorders.



result is a stroke that can cause paralysis or death. Arteriosclerosis is a typical disorder of aging, but its severity varies in different persons.

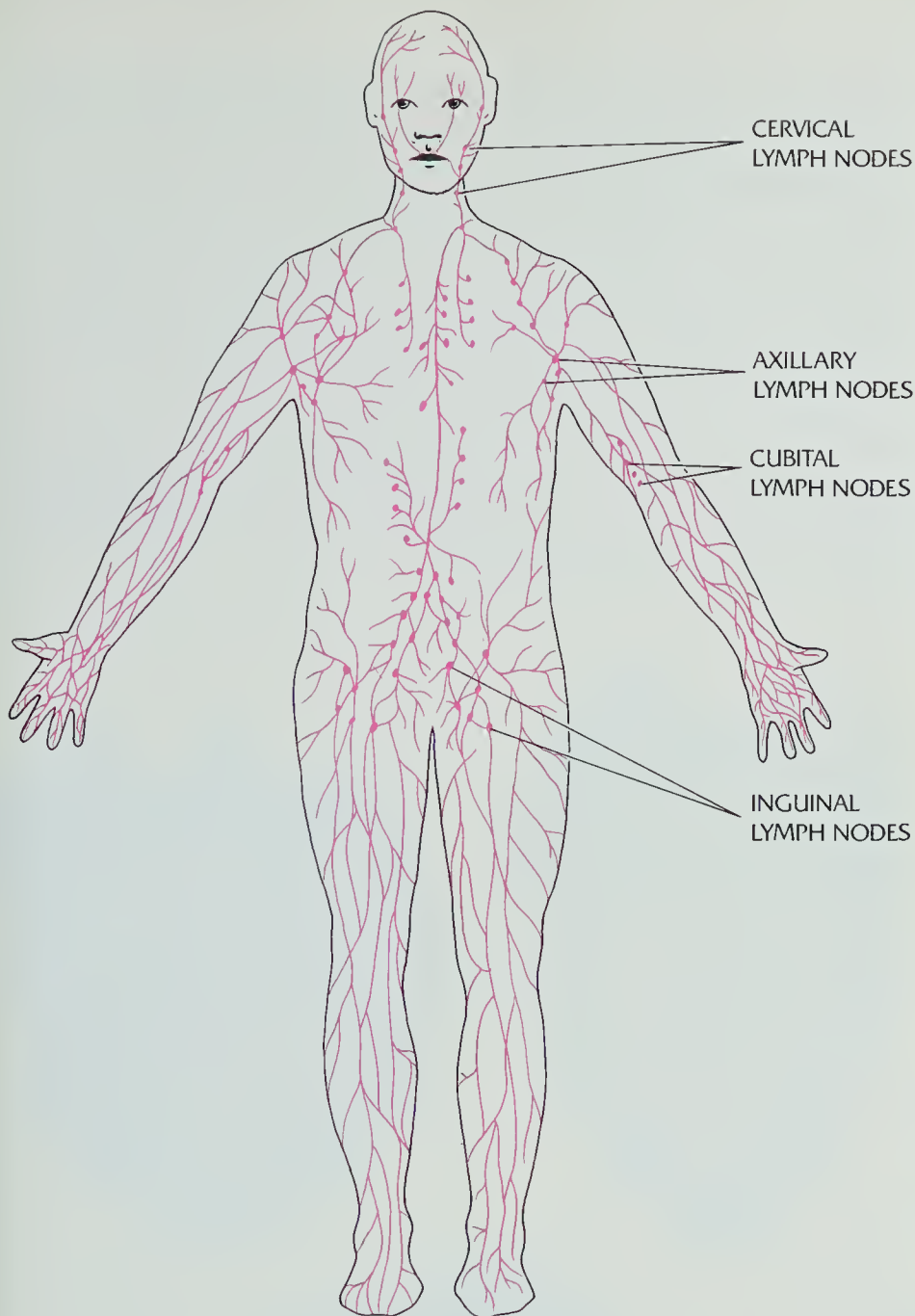
A second circulatory disorder is called **atherosclerosis** (ath əɹ ō sklə rō'sis). This is a common problem in North America. It is a condition caused by a buildup of fatty material inside the arteries. The buildup narrows the opening inside the arteries, causing an increase in blood pressure. In turn, an increase in blood pressure can result in ruptured arteries and a stroke. The fatty buildup also creates a rough inside wall. Blood flowing against the rough surface will sometimes form clots. If a clot plugs up a small artery in the brain, a person can suffer a stroke. If a clot plugs up a branch of a coronary artery, which serves the heart, the person can suffer a **coronary** (kôr'ə ner ē) **heart attack**, or "coronary."

A third type of disorder occurs when there is a weak spot in a main artery, such as the aorta. At the weak spot the artery balloons out, causing an **aneurysm** (an'yə riz əm), or swelling. If these are discovered, surgeons can often cut them out and patch the artery with an artificial tube. But any aneurysm that is not discovered is extremely dangerous. It can rupture and cause instant death by internal bleeding.

MAIN IDEA

Some plasma is contained in the lymph vessels. Lymph nodes are active in defense of the body against infectious invaders.

34–19 The lymphatic circulation When plasma leaves the capillaries and bathes the cells, it may return to the systemic circulation. However, some of this fluid remains in the tissues and is returned to the blood by another route, called the **lymphatic** (lim fat'ik) **circulation**.



SCIENCE TERMS

systemic circulation
 arterial blood
 systole
 diastole
 aorta
 semilunar valve
 stethoscope
 coronary arteries
 venous blood
 superior vena cava
 inferior vena cava
 pulmonary artery
 pulmonary veins
 arteriosclerosis
 atherosclerosis
 coronary heart attack
 aneurysm
 lymphatic circulation
 lymph capillaries
 lymph
 lymph nodes

FIGURE 34-11

The locations of the lymph nodes are illustrated at left.

Besides blood capillaries, most tissues also have **lymph** (limf) **capillaries**. The lymph capillaries are more permeable than blood capillaries. Fluids from the tissues—including blood proteins that have escaped, foreign particles, and bacteria—can enter the lymph capillaries. Once inside the lymph capillary, the fluid is called **lymph**. You have seen fluid like lymph—it is the clear liquid in a blister.

The lymph capillaries come together and form larger lymph vessels. The lymph vessels are much like veins. They have valves, and the lymph is pushed forward by the squeezing action of muscles. Eventually the lymph enters two main lymph vessels, which empty into large veins near the heart. Fats absorbed in the small intestine also enter the lymph vessels and with the lymph enter the blood.

ANSWERS TO CHECK YOUR FACTS

1. Arterial blood is oxygen-rich blood. Systole of the left atrium opens the bicuspid valve and forces blood into the left ventricle.
2. The process of relaxing and returning to normal size after systole. Just before diastole,

systole occurs in the atrium.

Just after diastole, systole occurs in the ventricle.

3. The bicuspid shuts and the semilunar valve opens.

4. Backward pressure from the blood in the aorta shuts it when diastole occurs in the left ventricle.

5. The closing of the bicuspid, tricuspid, and semilunar valves.

The structure of the heart in representatives of the five classes of vertebrates—fish, amphibian, reptile, bird, and mammal—is shown.

In many parts of the body there are enlargements in the lymph vessels. These are specialized structures called **lymph nodes** (nōdz). The lymph nodes have four functions. (1) They filter out of the lymph any foreign particles that were picked up from the tissues. (2) They produce lymphocytes, which are leukocytes that help combat infections. (3) They contain macrophages that kill bacteria. (4) They produce antibodies to fight infections.

When there is a serious infection in the body, many macrophages migrate to the lymph nodes. After a period of time this can cause the lymph nodes to swell. During such an infection, swollen lymph nodes in the neck, groin, and underarm area can often be felt.



CHECK YOUR FACTS

1. What is arterial blood? How does it get into the left ventricle?
2. What is diastole? What occurs just before and after diastole of the left atrium?
3. When systole occurs in the left ventricle, what two structures are moved?
4. How and when does the semilunar valve shut?
5. What causes the sound of a beating heart?

SUMMARY

Adult humans have about 5 L of blood in their body. It carries food, oxygen, wastes, and hormones. It helps regulate body heat and defends the body against infectious disease agents. Blood is about half plasma and half formed elements. The formed elements include the erythrocytes, the leukocytes, and noncellular platelets. The heart has four chambers and is surrounded by the pericardium. Arteries are designed to carry large surges of blood from the heart. They have thick and elastic walls. Capillaries are the vessels that supply the cells. Most blood is contained in veins.

REVIEW QUESTIONS

1. What is the function of blood?
2. Describe what blood is made of.
3. Describe the functions of the three basic types of leukocytes.
4. Explain why atherosclerosis increases the chance of having a clot form in the bloodstream.
5. What are the four chambers of the heart? What vessels either enter or exit the chambers?
6. Describe how blood passes through the heart from the vena cava to the pulmonary artery.
7. Why is cardiac muscle tissue the ideal tissue to make up the heart?
8. Describe the systemic pathway.
9. What vessels carry oxygen-rich blood?
10. What are six functions served by the lymphatic system and its structures?

ANALYSIS AND APPLICATION

1. Why are injured arteries more serious than injured veins? Explain.
2. Which blood vessels can you observe on the inner surface of your elbow and forearm?

ANSWERS TO REVIEW QUESTIONS

1. To carry food and oxygen to the cells; to carry away wastes; to distribute hormones; to regulate body heat; and to fight infection.
2. The liquid plasma is made up of water, wastes, nutrients, and blood proteins. The formed elements include the red and the white blood cells and platelets.
3. See section 34–4.
4. The disorder is caused by a buildup of fatty material in the arteries. This buildup creates a rough inner wall that could trigger the platelets to form clots.
5. Right atrium—entered by the superior vena cava and the inferior vena cava. Right ventricle—exited by the pulmonary artery. Left atrium—entered by four pulmonary veins. Left ventricle—exited by the aorta.
6. See section 34–16.
7. It is aerobic muscle, and while it cannot perform without oxygen, it never tires because no lactic acid is built up by anaerobic respiration.
8. See section 34–15.
9. All arteries except the pulmonary artery, the arterioles, and the pulmonary veins.
10. The system (1) returns plasma to the bloodstream and (2) transports fats to the bloodstream. The lymph nodes (3) filter out foreign particles in the lymph, (4) produce lymphocytes, (5) kill bacteria with the macrophages they harbor, and (6) produce antibodies.

ANSWERS TO ANALYSIS AND APPLICATION

1. Because arterial blood is pumped out more rapidly and with greater force. Arterial blood loss is more difficult to control and repair.
2. Veins.

Investigation 54 from *Laboratory Investigations in Biology* can be done with this chapter.

35

Respiration



OBJECTIVES

- To trace the path of air from the nose or mouth to the alveoli in the lungs
- To understand that gas exchange occurs in the alveoli
- To describe the role of the diaphragm in breathing
- To appreciate the unique nature of asthma, emphysema, colds, and pneumonia
- To understand that the process of excretion is a homeostatic mechanism
- To discuss the significance of the nephron
- To explain how wastes from the kidneys are stored and eliminated from the body

and Excretion

Respiration

35-1 A term with dual meanings Respiration is a term that may be used to describe two different biological processes. One process occurs in cells and is sometimes called cellular respiration. This is the process that breaks down sugars, amino acids, or fatty acids and produces ATP for energy.

The second process is the exchange of gases between an organism and its environment. In the human, respiration brings oxygen from the air to the capillaries in the lungs, and carbon dioxide from the lung capillaries into the air. It is this gas exchange process that will be discussed in this chapter.

35-2 The respiratory system The respiratory system includes the nose, pharynx, trachea (windpipe), and lungs. The term *nose* actually refers to the external structure on our face. But the real working part of the nose is the interior region, which is made of three separate **nasal** (nā'zəl) **cavities**. The nasal cavities are lined with a **mucous membrane**, which is made up of ciliated cells that produce mucus. The mucus helps filter particles such as dust and bacteria out of the air. The cilia beat toward the pharynx and act like a broom. They sweep mucus and trapped particles into the pharynx where they are swallowed. The nasal cavities warm and moisten the air that passes through them.

The nasal cavities have ducts that connect with other regions of the head. Two of the ducts connect with the eye

MAIN IDEA

Respiration can refer to either cellular respiration or to gas exchange.

MAIN IDEA

The nasal cavities filter, warm, and moisten inhaled air. They are connected to the eye cavities, the sinuses, the pharynx, and the trachea.

SCIENCE BACKGROUND

Physiologists often describe four kinds of respiration: (1) pulmonary ventilation, or the movement of air from the environment to the alveoli; (2) the diffusion of gases from alveoli to and from the blood; (3) the transport of gases in the bloodstream to and from the body cells; and (4) the regulatory processes that make all of this work. In this chapter we are concerned only with pulmonary ventilation, which is the *respiration* of conventional pedagogy.

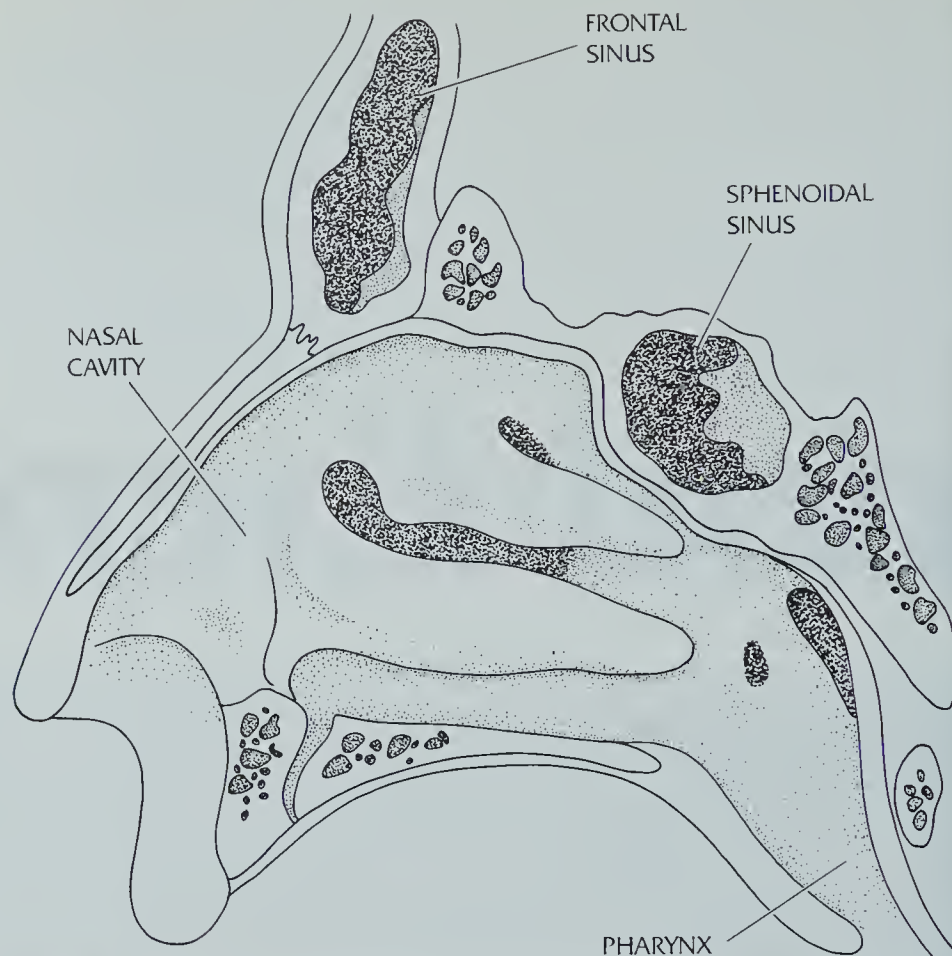


FIGURE 35-1 The relationship of the nasal cavity to the sinuses of the head is shown in this illustration.

cavities. They drain excess tears from the eyes into the nasal cavities. That is why crying or irritation of the eyes causes excess nasal drainage. Also connected to the nasal cavities are ducts from the **sinuses** (sī'nəs ez), which are air spaces in the facial bones. The sinuses have two functions. They make the skull bones lighter, and they help give your voice its proper sound. (Hold your nose and talk. You will see how your voice sounds when air does not move through any part of the nasal system.) Sometimes the sinuses become infected and excess mucus is produced. This mucus drains through the sinus ducts into the nasal cavities.

Air moves from the nasal cavities into the pharynx, a funnel-shaped cavity. It is the common pathway for both food and air. After air passes through the pharynx, it enters the trachea, which can be felt just below the larynx, or Adam's apple. The trachea is a hollow tube that is kept from collapsing by rings of cartilage. The trachea is the passageway that leads to the lungs.

SCIENCE BACKGROUND

The three main nasal cavities are divided by bony ridges called the superior concha, the middle concha, and the inferior concha. The sinuses are the frontal sinus, the sphenoid sinus, and the ethmoid sinus. The ducts that connect with the eyes are the nasolacrimal ducts.

35-3 The lungs The two lungs fill most of the cavity in the chest, or **thorax** (thôr'aks). Air enters the lungs through two bronchial tubes called **bronchi** (brong'kī), which divide from the end of the trachea. The bronchi soon branch and rebranch into smaller tubes called **bronchioles** (brong'kē olz). The bronchioles finally reach a dead end in small sacs called **alveoli** (al vē'ə li) (sing. *alveolus*). It is estimated that there are about 300 million alveoli in a normal person's lungs.

The alveoli are made up of flat cells and elastic connective tissue. Covering the outside of the alveoli is a network of capillaries from the pulmonary circulation. Erythrocytes in the pulmonary circulation pass through the capillaries single file, and the gas exchanges occur across the two layers of cells (one layer in the wall of the alveolus and the other in the wall of the capillary). It is estimated that all the blood in the body passes through the alveolar capillaries in just 1 min when the body is resting. During exercise all the blood may flow through them in just 10 to 15 s.

The lungs are surrounded by a double membrane called the **pleura** (plür'ə), sometimes the region between the

MAIN IDEA

Air enters the lungs through bronchi, whose branches reach to the alveoli. Gas exchange occurs between the pulmonary capillaries and the alveoli.

SCIENCE BACKGROUND

The maximum oxygen uptake can be increased by up to 12 times by increasing the volume of inspired air, by increasing the breathing rate, and by increasing the flow of erythrocytes through the lungs.

SCIENCE BACKGROUND

There are many macrophages in the lungs that are constantly busy phagocytizing bacteria particles that have been inhaled.

FIGURE 35-2 The major structures of the respiratory system in humans are identified in the figure below.

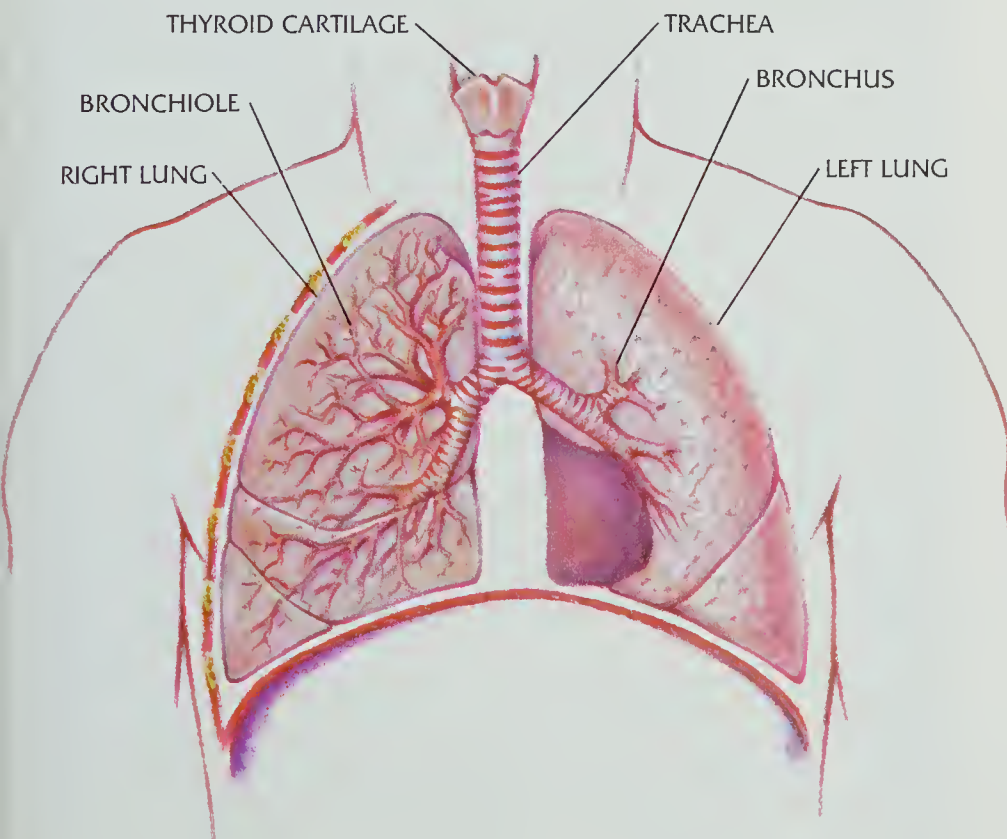
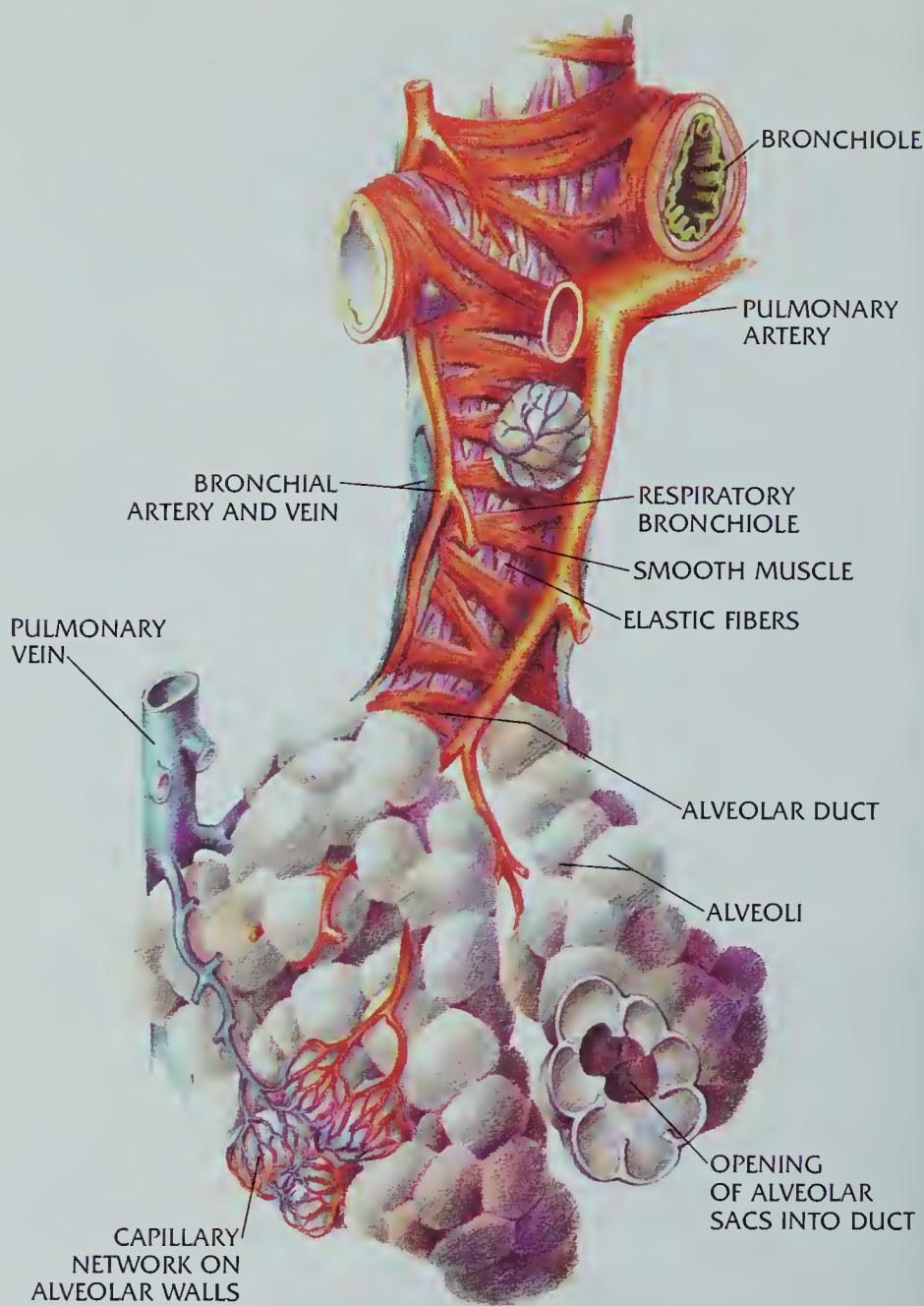


FIGURE 35–3

Red blood cells passing through the capillaries on the alveolar walls pick up oxygen and release carbon dioxide to the alveoli.



two membranes becomes irritated, causing a painful condition called pleurisy.

MAIN IDEA

Alternating inspiration and expiration are caused primarily by the diaphragm. Elastic tissue in the lungs aids in the expiration process.

35–4 The mechanics of respiration Respiration involves two processes. One is **inspiration** (in spə rā'shən), where air is taken into the lungs. The other is **expiration** (eks pə rā'shən), where air is forced out of the lungs.

Assisting with inspiration and expiration are certain muscles in the thorax and elastic tissue in the lungs. The main muscle is the **diaphragm** (dī'ə fram), which lies below the lungs. During inspiration the diaphragm con-

tracts into the abdomen, creating decreased air pressure in the thorax. This causes air to rush into the lungs. During expiration the diaphragm relaxes, and this helps force the air out of the lungs. Helping the diaphragm in movements of the thorax are the muscles between the ribs. They make the chest cavity larger during inspiration and smaller during expiration. The elastic tissue in the lungs also helps during expiration by compressing the lungs. When a person is resting, the elasticity does most of the work of expiration. The muscles are used mainly during the heavy breathing of exercise.

35–5 Disorders of respiration There are several common disorders of the respiratory system. One is **asthma** (az'mə), which is an allergic reaction of the bronchioles to something that is in the air. This can be caused by such things as plant pollen, dandruff from cats, and many different chemicals that may be polluting the air. The bronchioles react by increasing their secretions of mucus and by contracting the smooth muscle in their walls. This decreases the diameter of the bronchioles and makes respiration difficult.

SCIENCE TERMS

nasal cavities
mucous membrane
sinuses
thorax
bronchi
bronchioles
alveoli
pleura
inspiration
expiration
diaphragm
asthma
emphysema

MAIN IDEA

Asthma is an allergic reaction of the bronchioles. Emphysema is becoming more common—it destroys alveoli and blocks bronchioles. Colds and pneumonia cause excess fluids to build up and hinder gas exchange.



Some disorders of the lungs can be detected with the aid of a chest X ray.

ANSWERS TO CHECK YOUR FACTS

1. Cellular respiration, the process that produces ATP, and gas exchange.
2. Yes. They are connected by two ducts, through which excess tears from the eyes drain into the nasal cavities.
3. They make the skull bones lighter and they give our voice the proper sound.
4. A double membrane that surrounds the lungs.
5. It causes fluids to build up in the bronchioles and alveoli, thus preventing gas exchange.

MAIN IDEA

Excretion is a homeostatic mechanism because it removes the wastes that other body systems build up. Blood has the most important role in maintaining the homeostasis of the body.

A second type of disorder is **emphysema** (em fə sē'mə). This is a serious disease that is increasing rapidly for two reasons. It is a disease of aging, and the average age of our population is increasing. It is also caused by smoking, and the number of smokers has greatly increased in the past 50 years. Emphysema affects the lungs in two ways. First, many of the small bronchioles leading to the alveoli become plugged. Second, the alveoli at the ends of these bronchioles break down and simply disappear. The disease is progressive, which means that it can keep getting worse until the patient cannot get enough oxygen to stay alive. Practically every hospital is experiencing an increase in the number of severe emphysema patients who can only breathe with artificial respirators.

Colds and pneumonia are infectious diseases of the respiratory system. Colds are caused by viruses that infect the mucous membrane of the nasal cavities. There is no known cure for colds, except the body's own antibodies, which kill the viruses within a few days. Pneumonia may be caused by bacteria or viruses that infect the lungs. Either type of infection causes excess fluid to build up in the bronchioles and alveoli. This fluid prevents air from reaching the walls of the alveoli and thus prevents gas exchange. Pneumonia used to be a common killer of many people. Antibiotics and other medicines can now cure most forms of pneumonia.

CHECK YOUR FACTS

1. What two processes have the name *respiration*?
2. Are the nasal and eye cavities connected? Explain.
3. What are the functions of the sinuses?
4. What is the pleura?
5. How does pneumonia affect the lungs?

Excretion

35–6 Homeostasis and excretion Many different tissues and organs work to keep the internal environment of the body balanced. A stable condition in the internal environment of the body is called **homeostasis** (hō mē ə stā sis). Any process that works to keep the internal environment stable or constant is called a **homeostatic** (hō mē ə stāt'ik) **mechanism**. We discussed one homeostatic mechanism in the last chapter. We discussed how shifts in the blood flow through the skin can either cool the body or preserve its heat. The body should remain at a constant

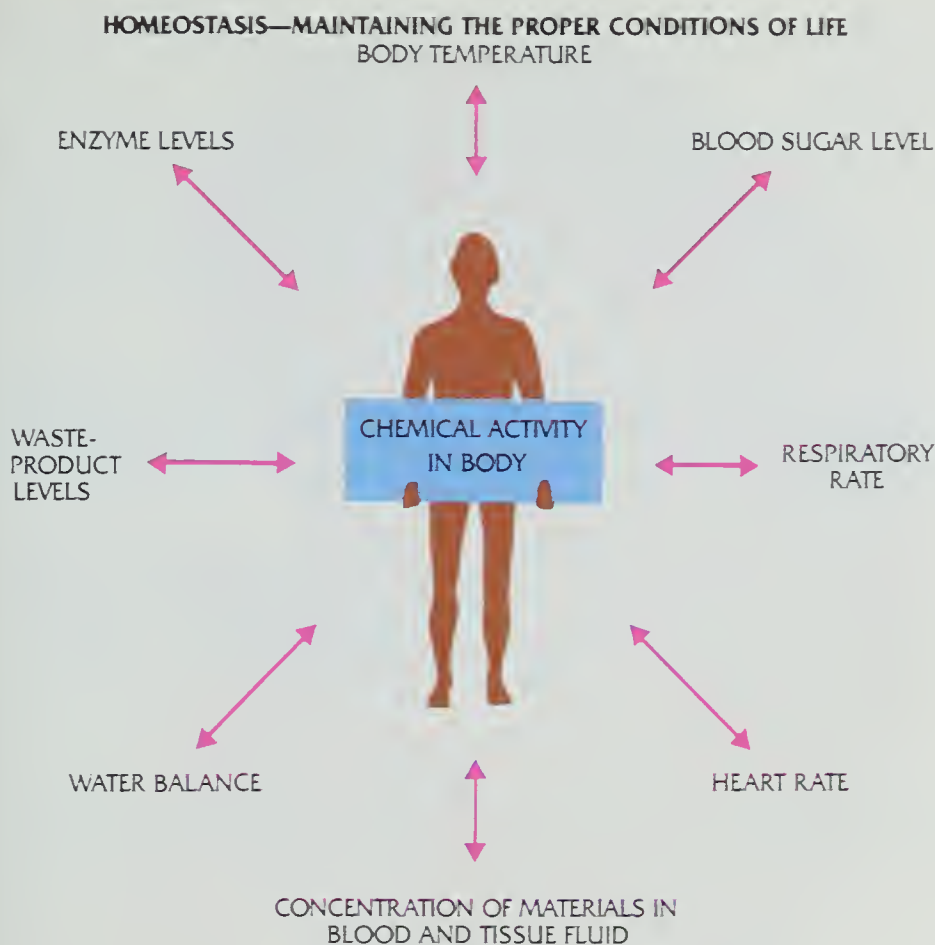


FIGURE 35-4 Numerous body processes operate to produce a condition of dynamic homeostasis.

temperature of about 37°C . A homeostatic mechanism that shifts the blood to and from the skin helps maintain that constant temperature.

Excretion (ek skrē'shən) is another type of homeostatic mechanism. Excretion is a process of eliminating materials from the body that could upset its homeostasis. For example, the respiratory functions that eliminate, or excrete, carbon dioxide from the body is a homeostatic mechanism.

The blood has the most important role in maintaining the homeostasis of the body. It provides a uniform environment for tissues from our fingers to our toes. But the blood itself is always changing. It takes in oxygen. It picks up carbon dioxide and digested food molecules. Most important are the other products that the blood picks up as it travels around the body. Some of these are by-products of metabolism, which is the total of all the different chemical reactions that go on in the body. These by-products include **urea** (yü rē'ə), a nitrogen by-product of protein metab-

olism. Also, at any given time the blood may have a surplus of certain useful chemicals, such as glucose, or certain vitamins.

Both the waste products and surplus chemicals have to be excreted from the blood so that it can function properly. The kidneys are responsible for the homeostatic mechanisms in the body that would rid the blood of such materials.

MAIN IDEA

The kidneys extract wastes from the blood and convert them to a form that can be excreted. The nephron is the functional unit of the kidney.

SCIENCE BACKGROUND

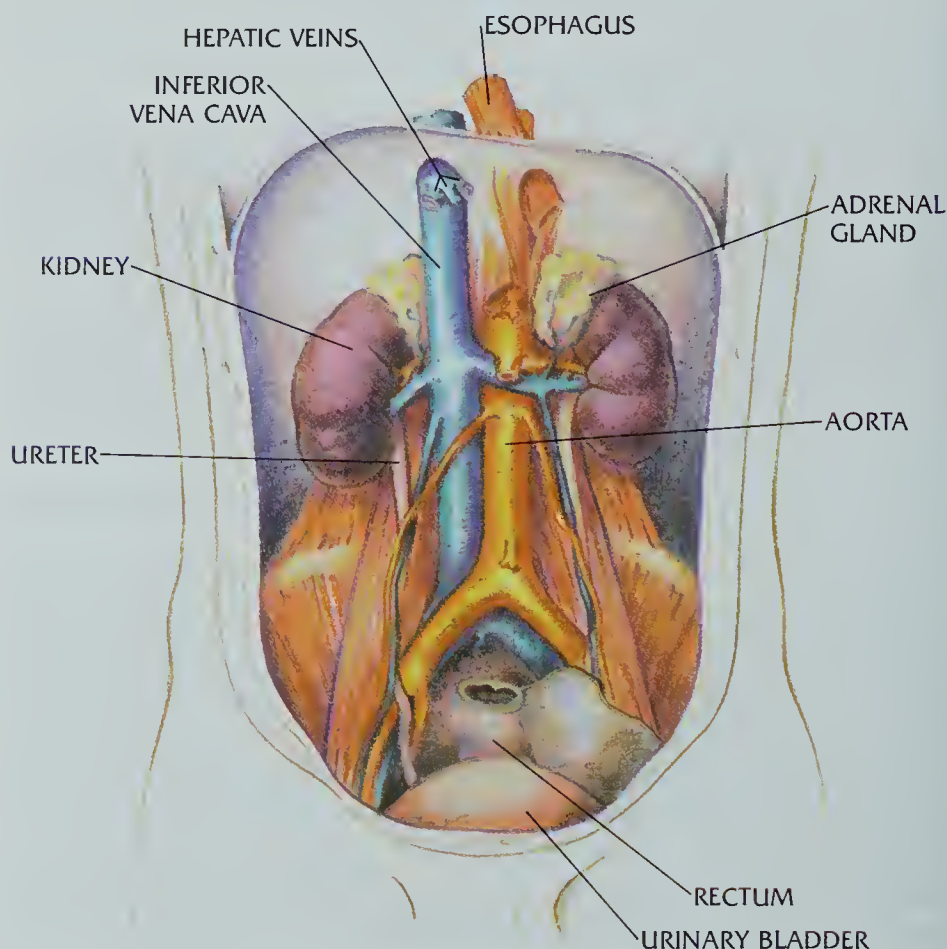
The kidneys are about 10 cm long and weigh about 300 g each. The approximate total length of all the nephrons is 120 km.

35-7 The kidneys The human has two kidneys, which are bean-shaped organs that lie at the back of the abdomen on each side of the spine. Their main function is to remove wastes from the blood.

Each kidney is made up of more than one million basic units called **nephrons** (nef' rons). It is the nephron that does all the work of the kidney. If one understands how the nephron works, one will understand the workings of the whole kidney.

FIGURE 35-5

The organs of the excretory system and the associated blood vessels are shown in this illustration.



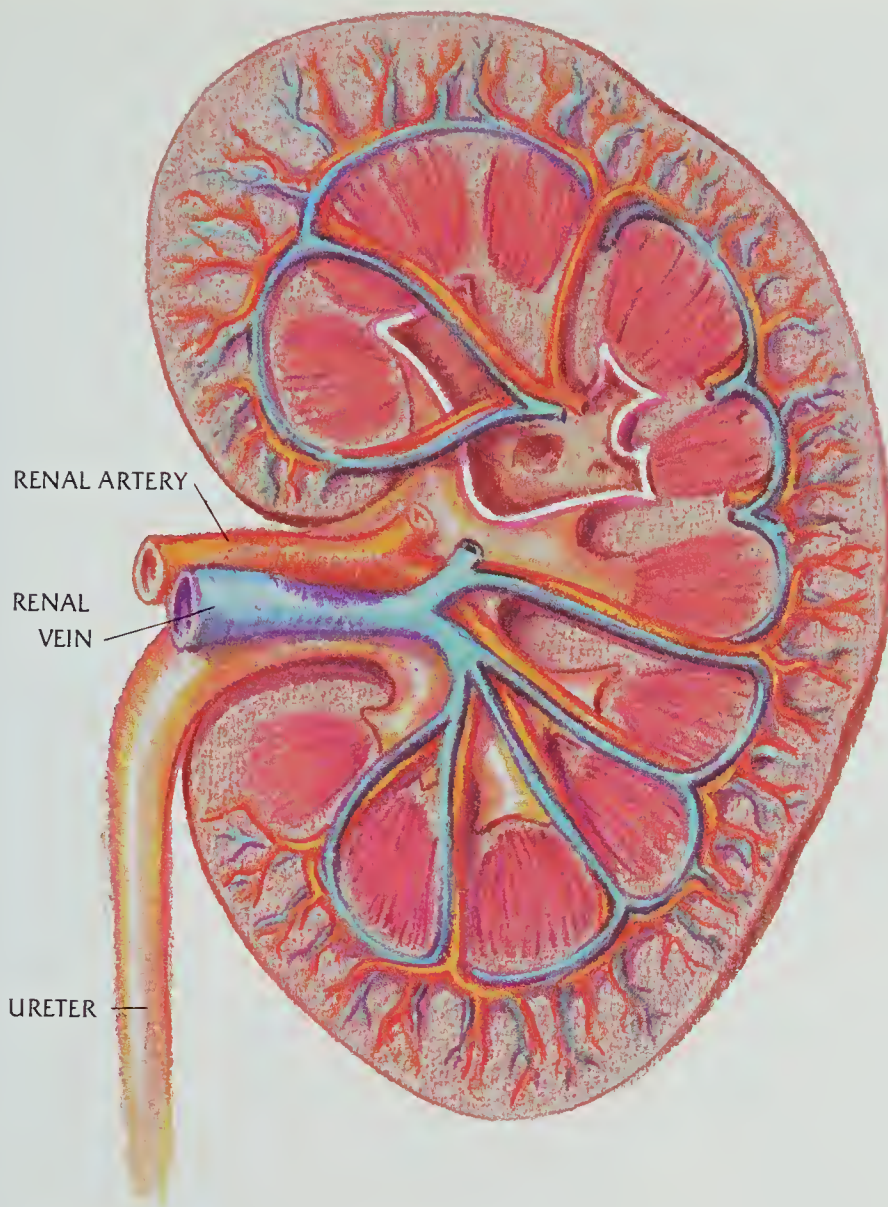


FIGURE 35-6

Blood enters the kidney through a renal artery, travels through a network of capillaries, and exits through a renal vein.

35-8 The nephron The nephron is a long tube with a vaselike cup at one end. The cup part of the nephron is called **Bowman's** (bō'mənz) **capsule**. In Bowman's capsule there is a tuft of capillaries that is shaped like a ball and is called the **glomerulus** (glə mer'ū ləs). The glomerulus is linked with a network of capillaries that surrounds the tube part of the nephron.

Blood enters the kidney from the aorta through the **renal** (rē'nəl) **artery**. Then, just within a short distance, the renal artery branches and rebranches into the capillaries of each glomerulus. This is a sudden slowdown for the blood, and the pressure is greater in the glomerulus

MAIN IDEA

Blood plasma is forced by pressure into the nephron where it is filtered and reabsorbed, then passed into the bloodstream. The filtered material exits the nephron in the urine.

SCIENCE TERMS

homeostasis
homeostatic mechanism
excretion
urea
nephrons
Bowman's capsule
glomerulus
renal artery
urine
ureters
urinary bladder
urethra
urinate

SCIENCE BACKGROUND

The pressure in the glomerulus forces about 100 times more plasma out of these capillaries than is forced out of capillaries in a muscle. In a healthy person there may be a small amount of one of the large blood proteins in the glomerular filtrate. This is serum albumin, and its presence may increase after severe muscular exercise or a cold bath. During diseases such as scarlet fever, pneumonia, and strep throat, the serum albumin level may also rise.

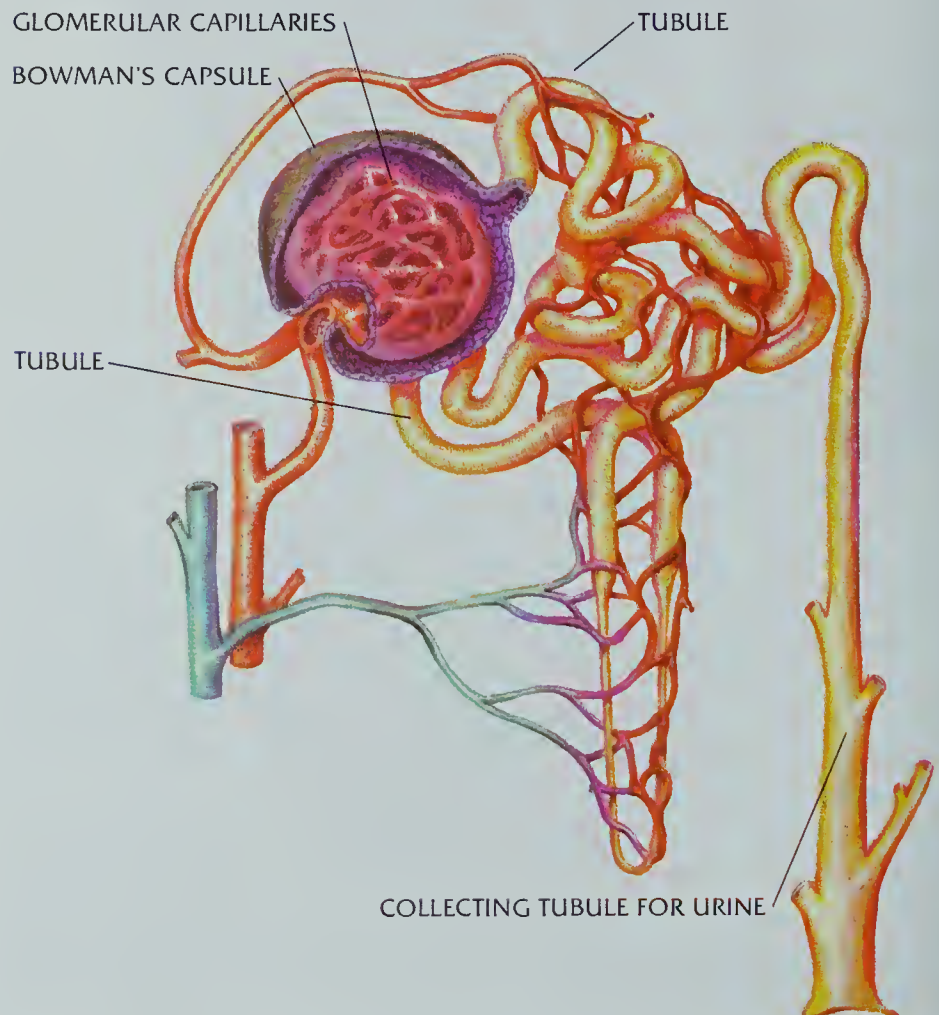
than in the other capillaries of the body. This pressure forces much of the plasma out of the blood, into Bowman's capsule, and then into the long tubule of the nephron. Only the formed elements, large proteins, and some plasma remain in the blood that flows out of the glomerulus.

About 180 L of plasma are forced out of the blood and into the nephrons each day. But only about 1 to 1.5 L of liquid actually come out the ends of the tubules. What happens to the other 178 to 179 L that enter the nephrons? This liquid is reabsorbed by the cells in the walls of the nephrons and is passed on to the capillaries that surround them.

The nephron works as a selective filtering device. Almost all the blood plasma is forced into the nephrons. Then the parts of the plasma that are needed by the body are reabsorbed into the blood. Urea and other unneeded

FIGURE 35-7

Plasma along with impurities is forced into the nephron, but only the plasma is reabsorbed. The impurities are collected as wastes.





In the event of kidney failure, the blood can be cleansed with an artificial kidney machine. The process is called hemodialysis.

chemicals are not reabsorbed. These chemicals, along with enough water to keep them dissolved, trickle out the ends of the nephrons. This fluid, now called **urine** (yür'ən), is collected in the hollow region of the kidney.

35-9 The urinary bladder Urine leaves the kidneys by tubes called **ureters** (yü rē'tərs). The ureters travel downward and empty into a muscular, saclike organ

MAIN IDEA

Urine leaves the kidneys and is stored in the urinary bladder. Sphincters between the bladder and the urethra control urination.

ANSWERS TO CHECK YOUR FACTS

1. Carbon dioxide, urea and other metabolic by-products, and sometimes surplus glucose or vitamins.
2. At the back of the abdomen on each side of the spine. The renal artery.
3. The nephrons.
4. Urine, which is urea and other waste chemicals dissolved in water.
5. Ureters are tubes that lead from the kidneys to the bladder. The urethra is the tube through which urine is excreted.

ANSWERS TO REVIEW QUESTIONS

1. Yes. It removes the carbon dioxide that could upset the homeostasis of the body.
2. The eye cavities, the sinuses, and the pharynx. Three.
3. The diaphragm is pushed up, the muscles in the ribs make the chest smaller, and the elastic tissue of the lungs compresses the lungs.
4. Two bronchial tubes enter the lungs and branch into many bronchioles, which end in air sacs called alveoli. The lungs are surrounded by a double membrane called the pleura.

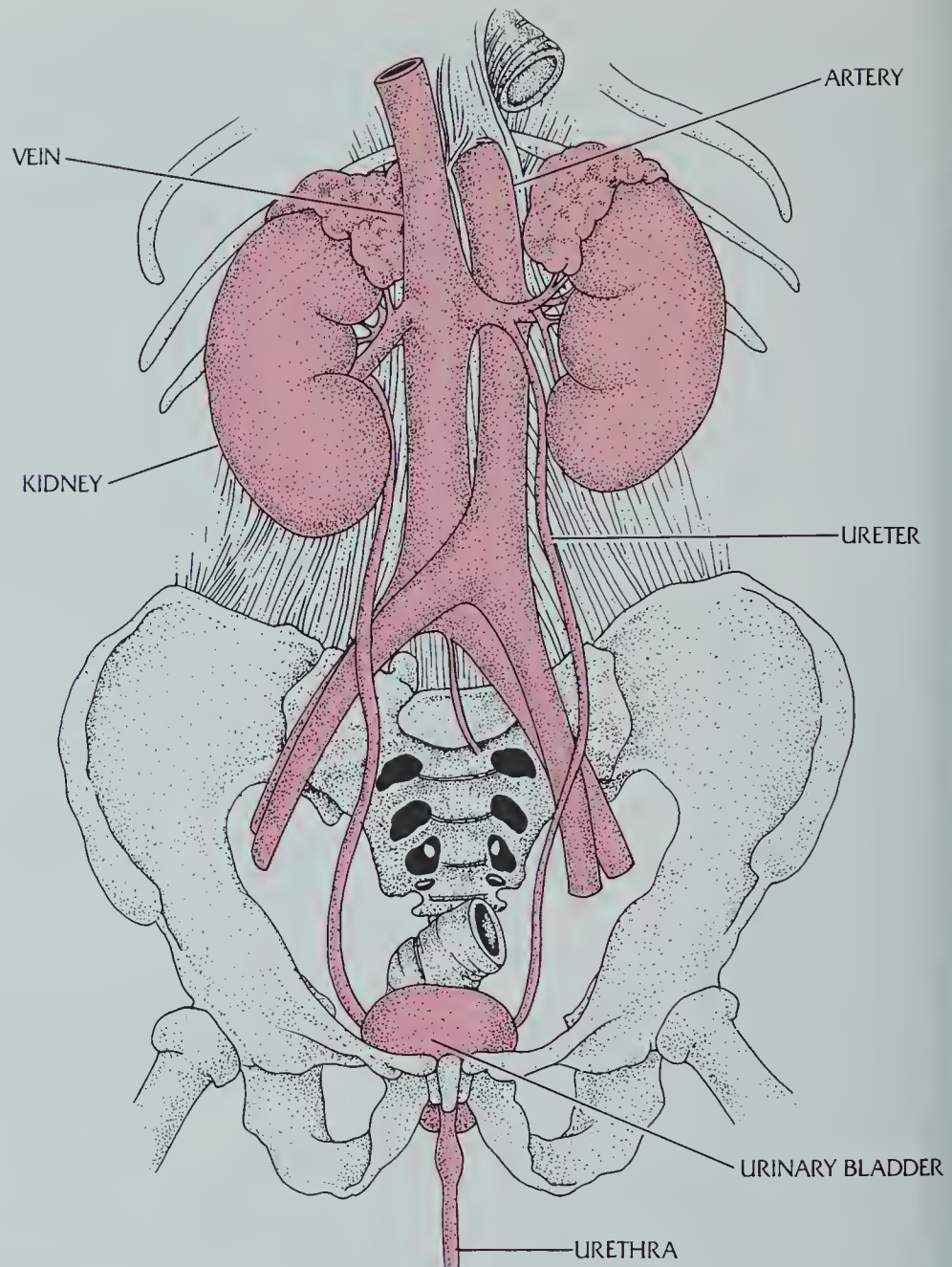


FIGURE 35-8 Following its formation in the kidneys, urine flows through the ureters to the urinary bladder where it may be stored for a time. It is eliminated from the body through the urethra.

called the **urinary** (yür'ə ner ē) **bladder**, or more simply, bladder. The bladder is a storage container for the urine. At the bottom of the bladder there are sphincters that close it off from the **urethra** (yü rē'thrə). The urethra is the tube leading from the urinary bladder to an external opening of the body. From time to time, as the bladder fills and stretches, it is necessary to **urinate** (yür'ə nāt). That is the process where urine is eliminated through the urethra.

CHECK YOUR FACTS

1. What are some of the wastes and surplus chemicals carried by the blood?
2. Where are the kidneys located? What artery supplies them?
3. What are the functional subunits of the kidney?
4. What leaves the ends of the nephrons and collects in the kidneys?
5. What are ureters? What is the urethra?

SUMMARY

The respiratory system in humans exchanges oxygen and carbon dioxide in the lungs. Air travels through the trachea and enters the lungs through bronchi, which branch into bronchioles. The site of gas exchange is the cluster of alveoli in the sacs at the ends of the bronchioles. Inspiration and expiration are caused primarily by the diaphragm and the elastic tissue of the lungs. Excretion is a homeostatic mechanism because it eliminates wastes that could upset the stability of the body. The kidneys, more specifically the nephrons, filter the blood.

REVIEW QUESTIONS

1. Is the respiratory system a homeostatic mechanism? Why?
2. To what three structures are the nasal cavities connected? How many nasal cavities are there?
3. What causes expiration?
4. Describe the structure of the lungs.
5. How do asthma, emphysema, and pneumonia affect the lungs?
6. What are some homeostatic mechanisms?
7. How does blood help maintain the homeostasis of the body?
8. Trace the path of red blood cells through the kidneys.
9. What happens to plasma in the glomerulus? In the nephron?
10. About 180 L of plasma are forced out of the blood and into the nephrons each day. How many liters are usually returned to the blood?

ANALYSIS AND APPLICATION

1. What happens when a person cries? What other things cause an excess of tears?
2. Doctors are seeing more and more elderly women with emphysema. What is one possible explanation?

5. Asthma causes the bronchioles to secrete more mucus and to contract the smooth muscles in their walls. Emphysema causes bronchioles to become blocked, and alveoli in these areas break down and disappear. Pneumonia causes excess fluid to build up in the bronchioles and alveoli.

6. The list is long, but some are as follows: the respiratory function of gas exchange; excretion; the mechanism that shifts blood to the skin area to regulate body heat; eating and digestion.

7. Besides regulating body heat, it keeps the amount of food, oxygen, carbon dioxide, and metabolic wastes relatively constant throughout the body.

8. They simply enter and exit through the capillaries of the glomerulus.

9. Much of it is forced out of the blood and into Bowman's capsule. In the nephron most of it is reabsorbed and returned to the bloodstream. The undesirable molecules are filtered out, dissolved in water, and deposited as urine into the hollow region of the kidney.

10. From 178.5 L to 179 L.

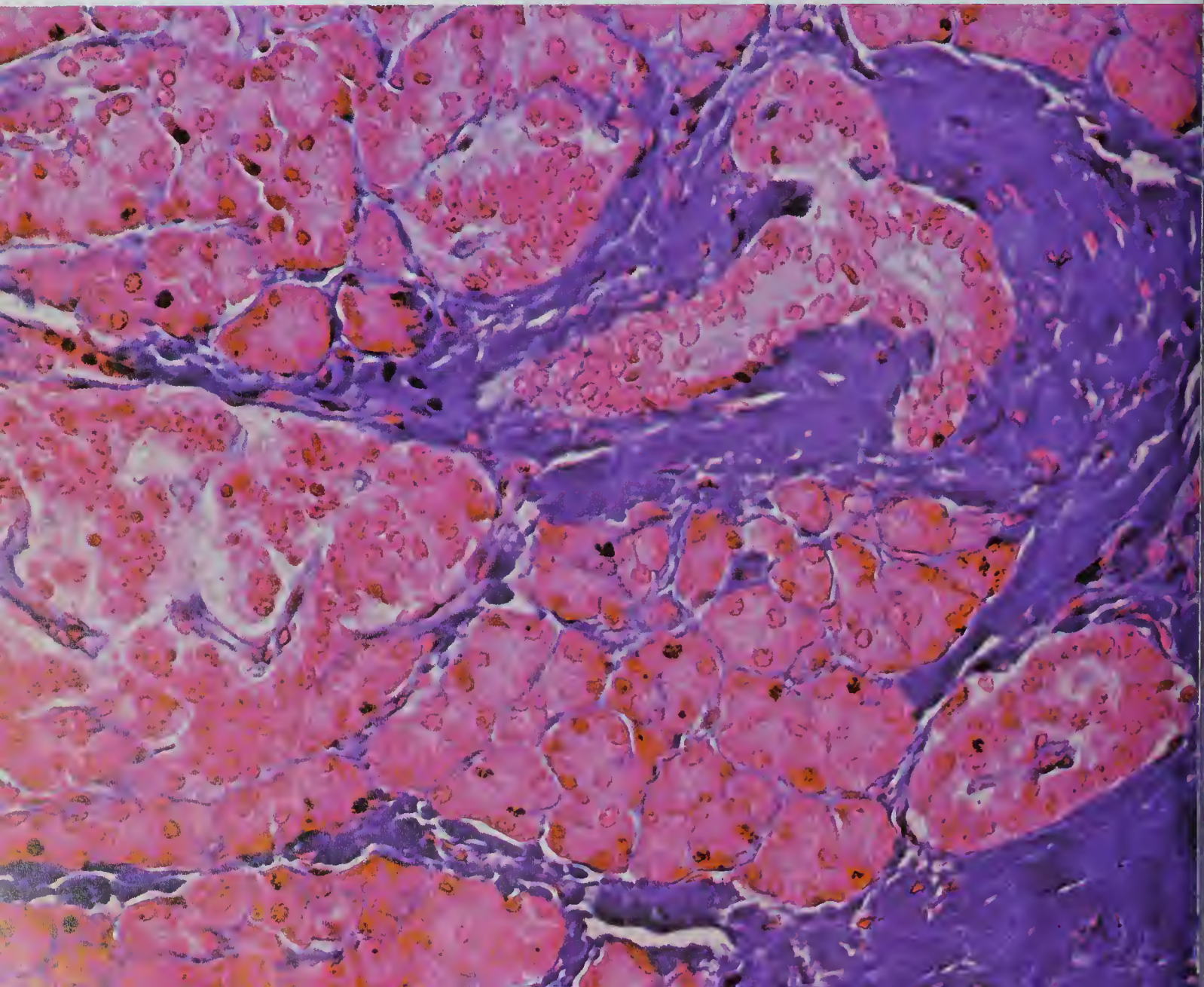
ANSWERS TO ANALYSIS AND APPLICATION

1. Their nose also "runs" because of the interconnection of the eyes and the nose. Many skiers and others moving through cold air have to use handkerchiefs over their nose because excess tearing is caused by the irritation of the cold air.

2. The number and percentage of women smokers increased dramatically from the 1930s to the 1950s. Now these women are entering the age bracket where emphysema starts to appear.

Investigation 55 from *Laboratory Investigations in Biology* can be done with this chapter.

36 *The Endocrine*



OBJECTIVES

- To understand the nature of the endocrine glands and the hormones
- To understand that the posterior lobe of the pituitary stores hormones that are actually produced in the brain
- To discuss the role of the six hormones produced by the anterior lobe of the pituitary
- To understand the role of the two hormones secreted by the posterior lobe of the pituitary
- To understand the role of the two hormones produced by the adrenal medulla and the adrenal cortex
- To explain the role of thyroxine
- To understand the role of the hormone produced by the parathyroid glands
- To discuss the role of insulin and glucagon in the control of blood sugar
- To appreciate that the kidneys produce a hormone that stimulates the production of erythrocytes and another that increases blood pressure

System

36-1 The nature of the system The endocrine system is made up of glands and specialized groups of cells that produce **hormones** (hôr'mônz) and secrete them directly into the bloodstream. A hormone is a chemical produced by the endocrine system that causes a physiological response in other cells. Endocrine glands are sometimes called ductless glands, because they secrete their product directly into the blood rather than through ducts.

Many of the body's homeostatic mechanisms involve hormonal action. Usually they involve the metabolic activities of tissues and organs. Some hormones speed up activities, while others slow them down.

In any discussion of endocrine glands or hormones there are two prefixes that are often used. The prefix **hyper-** means "over," or "excessive." For example, an overactive thyroid gland is described as a *hyperthyroid*. The other prefix, **hypo-**, has the opposite meaning. An underactive thyroid is a *hypothyroid*.

36-2 The pituitary One of the important endocrine glands is the **pituitary** (pi tü'ə ter ē) **gland**, which has a mass of about 0.5 g and is located under the brain. It is attached by a short stalk to a region of the brain called the **hypothalamus** (hī pə thal'ə mäs).

The pituitary gland has two regions, or lobes, which are made up of different tissues and secrete different hormones. The front, or **anterior** (an tir'ē ə) **lobe**, is linked to the hypothalamus by a group of capillaries. There is a one-way flow in the capillaries, so that secretions from the

MAIN IDEA

Endocrine glands produce hormones and secrete them into the bloodstream. Hormones are involved in many homeostatic mechanisms.

SCIENCE BACKGROUND

The science of endocrinology is advancing rapidly, but the precise nature of hormone action is still generally a mystery. Many hormones are involved at the molecular level in the action of membranes, genes, protein synthesis, and energy transformations.

MAIN IDEA

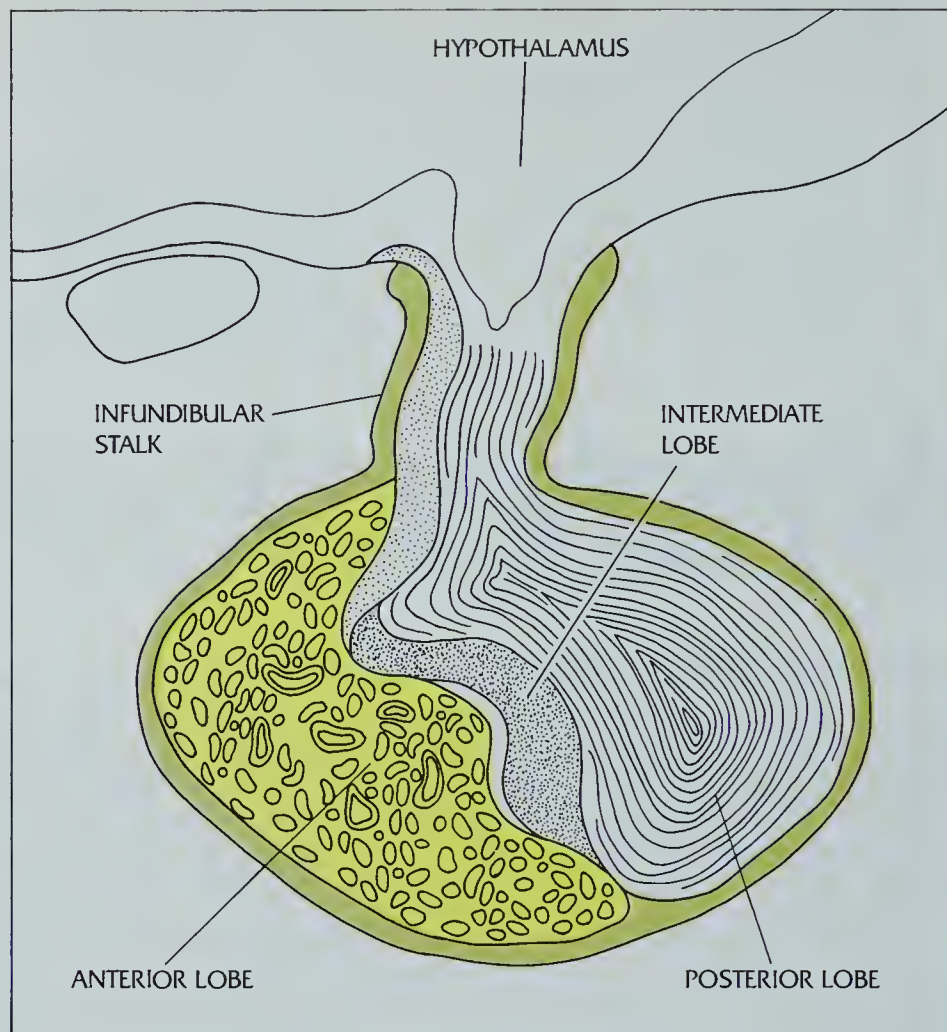
Releasing factors from the hypothalamus stimulate the production of hormones in the anterior lobe of the pituitary gland. The posterior lobe stores hormones that are produced by the hypothalamus.

SCIENCE BACKGROUND

The correct name for the pituitary is *hypophysis cerebri*. The anterior lobe is the adenohypophysis and the posterior lobe, the neurohypophysis. There is a small region between the two lobes called the *pars intermedia*.

FIGURE 36–1

The lobes of the pituitary gland are identified at right. The anterior lobe produces six hormones. The posterior lobe stores two hormones that are produced in the hypothalamus.



hypothalamus travel only *to* the pituitary. The hypothalamus produces chemicals called **releasing factors** that travel down into the anterior lobe and stimulate the release of hormones. The anterior lobe secretes six different hormones, and their secretion is stimulated by different releasing factors.

The back, or **posterior** (pos tir'ē ə) **lobe**, is only a storage gland for two hormones that are produced in the hypothalamus. These hormones travel from the hypothalamus along nerve fibers that extend into the posterior lobe.

MAIN IDEA

Of the six hormones produced by the anterior lobe, three are reproductive hormones. The others are ACTH, which stimulates the adrenal cortex; TSH, which stimulates the thyroid gland; and growth hormone, which increases protein synthesis and indirectly affects the growth of bones.

36–3 Hormones of the anterior lobe Of the six hormones produced by the anterior lobe, three are reproductive hormones. They stimulate the development of sperm and eggs and of milk in the mother's breasts.

Two of the other three hormones stimulate other endocrine glands. **Adrenocorticotrophic hormone**, or **ACTH**, stimulates the adrenal cortex, which is the outer layer of the adrenal glands. ACTH stimulates the adrenal

cortex to produce its hormones. The second stimulating hormone is **thyroid-stimulating hormone**, or **TSH**. It stimulates the **thyroid** (thī'roid) **gland** to increase the absorption of iodine from the bloodstream and to produce and secrete its hormone.

The sixth hormone produced by the anterior lobe is **growth hormone**. Growth hormone stimulates the production of proteins throughout the body. It stimulates the use of fat for energy.

Growth hormone has an indirect effect upon the growth of bones and cartilage. It stimulates the liver to produce a chemical that increases the rate of mitosis and cell growth in bones and cartilage. Abnormal secretions of growth hormone can result in abnormal growth patterns. Hyposecretion of the hormone causes the long bones of the arms and legs to grow slowly and to stop growing at an early age. This produces a "pituitary dwarf." Hypersecretion can cause the opposite effect—continued growth of the long bones and a "pituitary giant." Hypersecretion in adulthood, after the long bones have stopped growing, can cause bones of the face and vertebrae to grow more than normal. This condition, called **acromegaly** (ak rō meg'ə lē), produces a face with an enlarged jaw and brow and sometimes a humped back.

36-4 Hormones of the posterior lobe The hormones from the posterior lobe are really from the hypothalamus of the brain. However, they are secreted from the posterior lobe and are considered to be pituitary hormones. There are two of them, both short peptides that are made up of 8 amino acids.

One of the posterior lobe hormones has two names and is often thought of as two hormones because it produces two separate effects in the body. One name for the hormone is **vasopressin** (vas ō pres'in). It is sometimes used for medical purposes because it causes the arterioles to constrict. Under natural conditions, vasopressin is released during the severe bleeding of an injury. It helps to slow down blood loss and to maintain blood pressure. The other name for the hormone is **antidiuretic** (an tī dī yū ret'ik) **hormone**, or **ADH**. This hormone helps the body conserve water by causing reabsorption of water in the kidney tubules (nephrons). If the body is dehydrated, as it might be during warm weather, increased ADH causes more reabsorption of water in the kidneys. This causes the urine to be more concentrated. If the body has a surplus of water, ADH production will decrease and less water will be reabsorbed by the kidneys.

SCIENCE BACKGROUND

The three trophic hormones associated with reproduction are follicle-stimulating hormone (FSH); prolactin, which stimulates milk production; and luteinizing hormone (LH) in females and interstitial cell-stimulating hormone (ICSH) in males. The releasing factors have proved that hormone control is intimately associated with the brain and the nervous system—something investigators had suspected for years but had not been able to prove. A seventh hormone, melanocyte-stimulating hormone, is common in many vertebrates, but its role in pigmentation changes in the human is not well understood.

MAIN IDEA

A hormone secreted by the posterior lobe causes arterioles to constrict, slowing blood loss from an injury. It also affects the amount of water the body loses as urine.

SCIENCE BACKGROUND

The hormones from the hypothalamus migrate to the posterior lobe through the non-myelinated nerve fibers of the hypothalamo-hypophyseal tract. The hormones of the posterior lobe, as well as many other hormones, bind to serum proteins—mostly to globulins, which help keep the hormones from being filtered out of the blood in the kidney nephrons.

Oxytocin is sometimes given to stimulate or increase the strength of uterine contractions during childbirth.

The second hormone of the posterior lobe is **oxytocin** (ok si tō'sin). It functions in the female during and after childbirth.

MAIN IDEA

The adrenal medulla produces epinephrine and norepinephrine. These hormones act mainly to prepare the body for physical action.

SCIENCE BACKGROUND

Epinephrine is the physiological name; *adrenaline*, the proprietary name. The students should probably discuss all six effects of epinephrine to see how the body prepares for "fight or flight."

The adrenal cortex is often considered to be a highly specialized type of sympathetic ganglion, since it releases the same chemicals (catecholamines) that are released by the sympathetic nervous system, and since that system is the original embryological source of the tissue. Some authorities actually unite the two in a sympatheticoadrenal system.

As a constrictor, norepinephrine is 50 percent more powerful than epinephrine.

36-5 The adrenal glands The **adrenal** (ə drē'nəl) **glands** are small glands that lie above or near the kidneys. The adrenal glands are made up of two parts. Each part produces its own unique hormones.

The inner part of the adrenal gland is called the **medulla** (mi dul'ə). It produces two hormones that are called "fight or flight" hormones. They have this name because they stimulate the whole body to be ready for physical action.

The main hormone of the adrenal medulla is called **epinephrine** (ep ə nef'rin), or **adrenaline**. It is a powerful hormone that has six effects upon the body:

1. It causes the heart to beat faster and increase the force of its contractions.
2. It causes the selective constriction and dilation of arterioles. It causes those of the skin, mucous membranes, and kidneys to constrict. It causes those of the heart, skeletal muscles, and lungs to dilate.

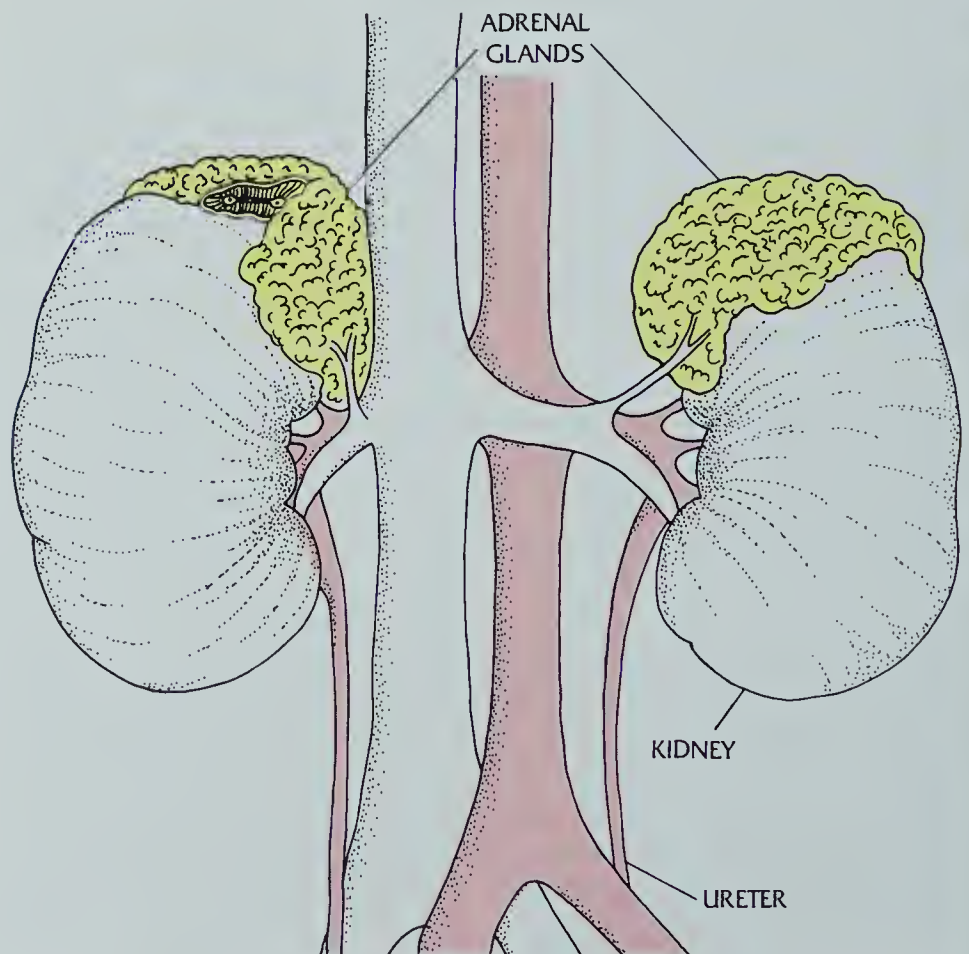


FIGURE 36-2
One adrenal gland lies above each kidney.

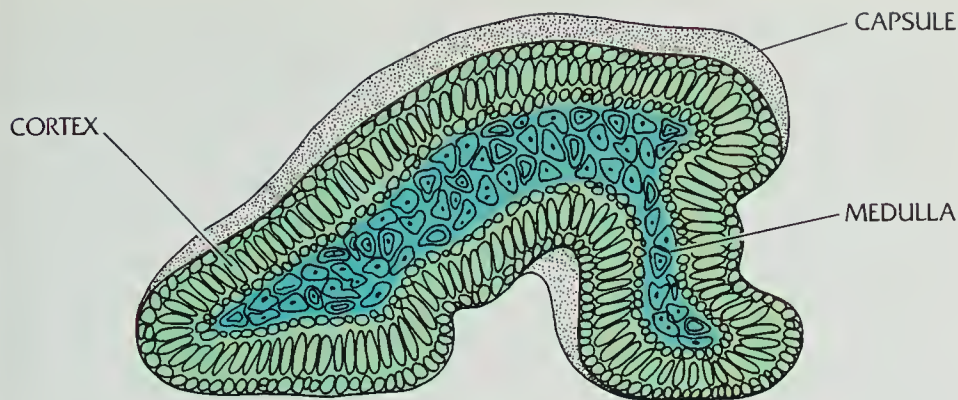


FIGURE 36-3

The hormones of the medulla, epinephrine and norepinephrine, prepare the body for physical action. Cortisol, produced in the cortex, is necessary for the body to deal with stress.

3. It selectively stimulates and inhibits almost all the smooth muscles in the body. It stimulates those of the spleen, digestive sphincters, hair follicles, and eye. It inhibits movement of smooth muscles in the stomach, intestines, bronchioles, and bladder.

4. It stimulates the nerves of the brain and spinal cord, making the body more aware and alert to the environment.

5. It causes the skeletal muscles to have increased strength and endurance.

6. It increases the energy metabolism inside cells and causes an increase in blood sugar by releasing stored carbohydrates.

The second hormone produced by the adrenal medulla is called **norepinephrine** (nôr ep ə nef'rin). It is a powerful constrictor of the arterioles and supplements the effect of epinephrine. It also has a role in releasing fatty acids from stored adipose tissue.

Epinephrine is widely used in medicine for certain emergencies. It is used to stop minor bleeding, such as in nosebleeds and during minor surgery. It is used to ease the symptoms of asthma because it inhibits the bronchiole muscles. Its most dramatic use is during heart stoppage, when it is injected directly into the heart. Sometimes it can start the heart beating again.

36-6 The adrenal cortex The outer region of the adrenal glands is called the cortex. A person can live without the adrenal medulla but not without the cortex, unless its hormones are given regularly. The hormones of the cortex are essential for life.

One of the hormones of the adrenal cortex is **cortisol** (kor'tə sōl). (The synthetic preparation of this hormone is called cortisone; it is converted to cortisol in the body.) Cortisol has numerous effects upon the body. Generally it stimulates various functions of the body so that it can tolerate stress. Production of cortisol is stimulated by condi-

SCIENCE BACKGROUND

The hormones of the cortex are steroids that are synthesized from esterified cholesterol. The assessment of hormonal action from the adrenal cortex has been extremely difficult because of the many intermediate synthetic products that get into the bloodstream and have partial activity.

Prolonged stress causes hypertrophy of the adrenal cortex and a loss of the body's stress defenses. Somehow vitamin C is related to the reserve material needed for hormone synthesis, but the relationship is unknown.

MAIN IDEA

The adrenal cortex produces the essential hormones cortisol and aldosterone.

SCIENCE BACKGROUND

The chemical name of thyroxine is tetraiodothyronine. The main effect of thyroxine is upon the basal metabolic rate (BMR). The BMR in myxedema may be 30 to 45 percent below normal. In hyperactivity it may be up to 50 to 75 percent.

MAIN IDEA

TSH from the pituitary causes the thyroid gland to produce thyroxine, which speeds up metabolism. Abnormal secretions of thyroxine can lead to serious disorders.

tions that stress the body, such as cold, heat, physical injury, and prolonged danger. Hyposecretion of cortisol results in **Addison's** (ad'ə senz) **disease**, which causes the body to have less tolerance to stress and a tired feeling.

The other major hormone of the adrenal cortex is **aldosterone** (al dos'tə rōn). It helps the kidney nephrons to control the homeostasis of sodium ions and potassium ions in the blood. If there are too many ions, they will be excreted in the urine. If there are too few, they will be reabsorbed in the tubule of the nephrons and put back into the blood.

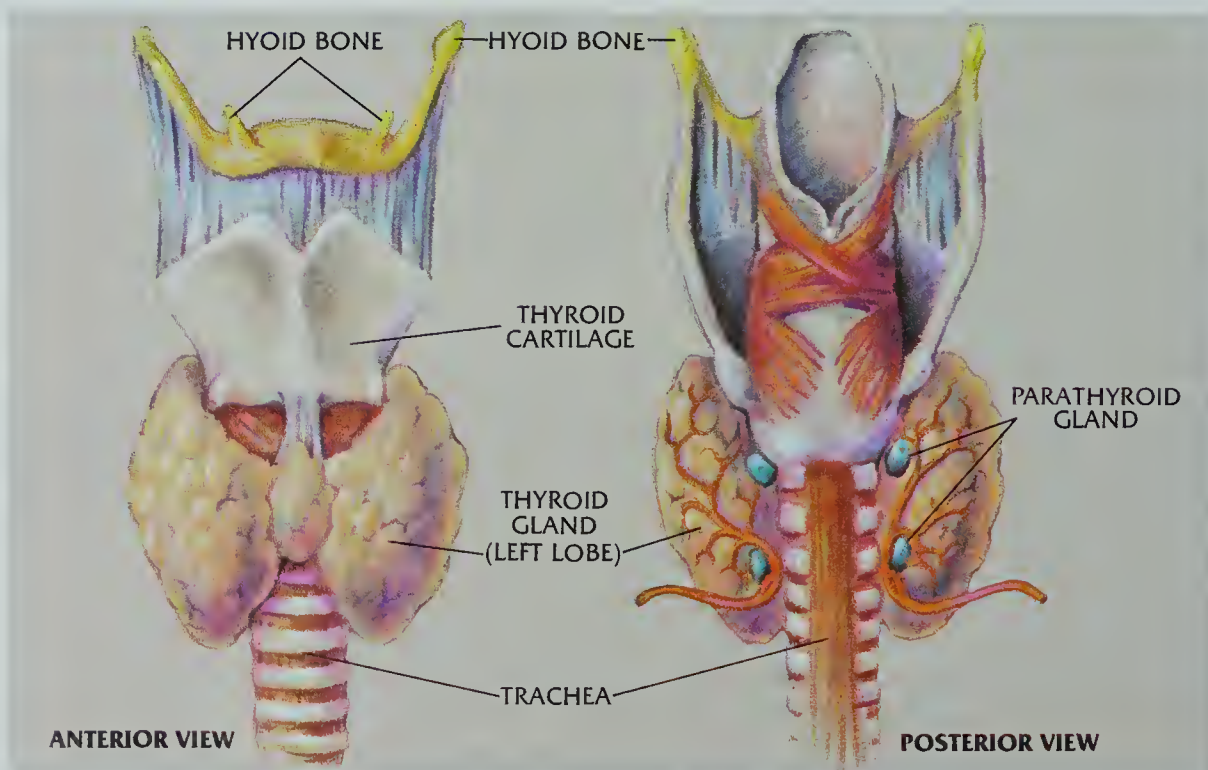
36-7 The thyroid The **thyroid gland** is in the neck just below the larynx. It has two lobes, one on each side of the trachea. They are connected by a narrow band of thyroid tissue. When stimulated by TSH from the pituitary, the thyroid takes iodine from the blood and makes a hormone called **thyroxine** (thī rok'sēn). TSH also stimulates the secretion of thyroxine into the bloodstream, where it has very strong effects upon the body.

Thyroxine increases the speed of metabolism in the body. Especially stimulated are the cellular respiration reactions that occur in the mitochondria of cells.

Abnormal secretions of thyroxine cause problems in the body. Hyposecretion during childhood causes a condition called **cretinism** (krē'tə niz əm). A victim of cretinism is underdeveloped, much smaller than normal, and mentally retarded. Hyposecretion in an adult causes a condition

FIGURE 36-4

The locations of the thyroid gland and the parathyroid glands are identified in this illustration.



called **myxedema** (mik sə dē'mə). In extreme cases of myxedema the person is obese, tired, and disinterested; has a slow heartbeat; and may be mentally dull. Hypersecretion of thyroxine is like turning up the body thermostat. Metabolism can greatly increase, causing increased heat production, loss of weight, nervousness, loss of sleep, and increased appetite. An extreme symptom is bulging eyes and widely dilated pupils. Fortunately, there are medical treatments for both abnormal conditions.

Another abnormal condition of the thyroid is **simple goiter** (goi'tər). This is an abnormally large growth of the thyroid. It may occur if there is not sufficient iodine in the diet to manufacture enough thyroxine. The thyroid responds to this shortage by growing larger. Simple goiter is rare in modern societies because iodine is now added to salt, and most people use this iodized salt on their food.

36-8 The parathyroids There are four **parathyroid glands** embedded in the thyroid gland. They are small—only about 2 to 4 mm long—and very important in the body. Removal of the parathyroids, without supplemental treatment, can cause death.

The parathyroids produce a hormone called **parathormone** (par ē thôr'môn). This hormone controls the homeostasis of calcium and phosphorous in the blood. A hypersecretion causes poor bones and teeth because of a lack of calcium. Hyposecretion causes the nervous system to be excitable, with muscular twitching and spasms.

36-9 The pancreas The pancreas is a dual-function gland. It produces digestive enzymes that flow through ducts into the small intestine. It has specialized tissue that produces hormones, which go directly into the bloodstream. This specialized tissue is called the **islets** (ī'lets) **of Langerhans** (läng'ər häns).

One hormone produced in the islets of Langerhans is **insulin** (in'sə lin). It is a protein that helps regulate the quantity of sugar in the blood. The function of insulin is to decrease the blood sugar and cause it to be stored in the form of glycogen. Glycogen is a polysaccharide that is stored in the liver and in muscle tissue. A hyposecretion of insulin causes the blood sugar level to rise. This causes a condition called **hyperglycemia** (hī pēr glī sē'mē ə). The excess sugar is excreted by the kidneys, and this sets off a chain of events that can lead to death in extreme cases. The disease caused by hyposecretion of insulin is called **diabetes mellitus** (dī ə bē'tis mel'ə təs), and it can be treated with regular injections of insulin.

SCIENCE TERMS

hormones
hyper-
hypo-
pituitary gland
hypothalamus
anterior lobe
releasing factors
posterior lobe
adrenocorticotrophic hormone (ACTH)
thyroid-stimulating hormone (TSH)
thyroid gland
growth hormone
acromegaly
vasopressin
antidiuretic hormone (ADH)
oxytocin
adrenal glands
medulla
epinephrine
norepinephrine
cortisol
Addison's disease
aldosterone
thyroxine
cretinism
myxedema
simple goiter
parathyroid glands
parathormone
islets of Langerhans
insulin
hyperglycemia
diabetes mellitus
glucagon
hypoglycemia
prostaglandins
erythropoietin
renin

MAIN IDEA

The islets of Langerhans in the pancreas produce insulin and glucagon—hormones that control the level of blood sugar

FIGURE 36–5

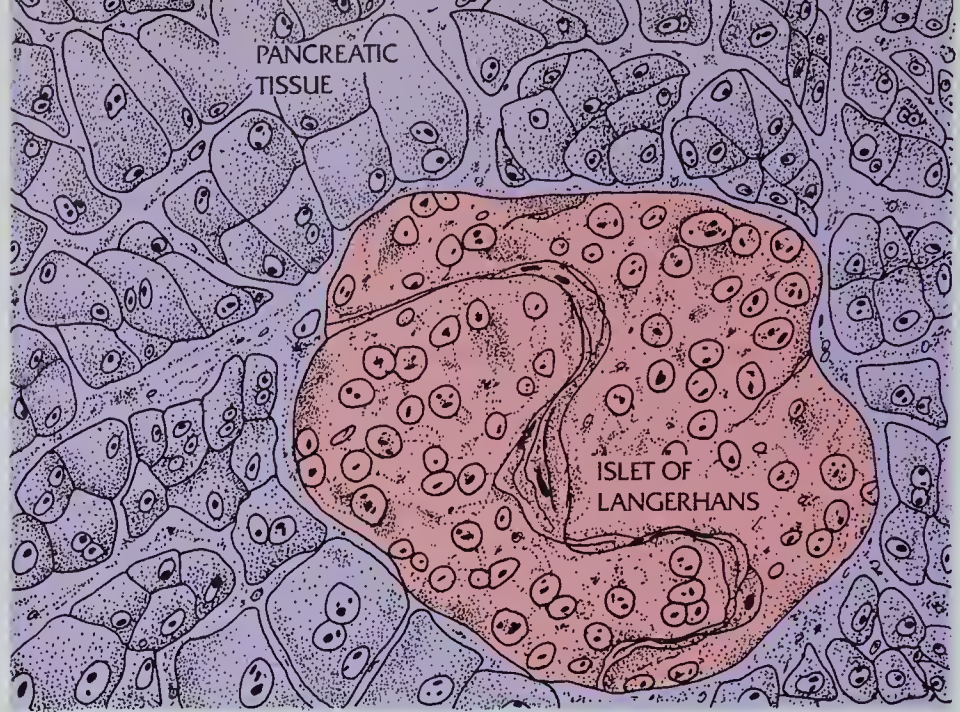
The islets of Langerhans, scattered throughout the pancreatic tissue, produce the hormones insulin and glucagon.

ANSWERS TO CHECK YOUR FACTS

1. A chemical produced by an endocrine gland or special group of cells that causes a physiological response in other cells. Endocrine glands.
2. *Hypo-* means under or deficient. *Hyper-* means over or excessive.
3. The hypothalamus is attached by a short stalk to the pituitary. It secretes hormones that travel along nerve fibers to the posterior lobe of the pituitary where the hormones are stored. Releasing factors from the hypothalamus travel to the anterior lobe of the pituitary, where they stimulate the secretion of hormones.
4. TSH causes the thyroid gland to increase the absorption of iodine and to produce and secrete thyroxine. ACTH stimulates the adrenal cortex to produce cortisol and aldosterone.
5. The growth hormone stimulates protein synthesis and the breakdown of fat for energy. It also stimulates the liver to produce a chemical that increases the rate of mitosis and cell growth in bones and cartilage. Acromegaly is a condition that produces a face with an enlarged jaw and brow, and sometimes a humped back. It is caused by the hypersecretion of growth hormone in adulthood.

ANSWERS TO REVIEW QUESTIONS

1. As vasopressin, it causes arterioles to constrict. It causes the nephrons to reabsorb more water. In the hypothalamus.



The other hormone produced in the islets of Langerhans is called **glucagon** (glū'kə gon). It has the opposite effect of insulin. Glucagon causes glycogen to be converted to glucose and sent into the bloodstream. A low blood sugar level, called **hypoglycemia** (hī pō glī sē'mē ə), stimulates the release of glucagon, which, in turn, causes the blood sugar level to rise.

36–10 Other hormones A group of hormones called **prostaglandins** (pros'ta gland inz) are found in many organs throughout the body. They exist for a very short time in the bloodstream and have been difficult to collect and study. They produce a wide variety of effects.

The kidney produces two hormones in addition to its function as a blood cleanser. One hormone, called **erythropoietin** (i rith rō poi'ə tin), stimulates the red bone marrow to produce more erythrocytes, or red blood cells. The other hormone is called **renin** (rē'nin), which causes an increase in the blood pressure.

CHECK YOUR FACTS

1. What is a hormone? What are ductless glands?
2. What do the prefixes *hypo-* and *hyper-* mean?
3. Describe how the structure and function of the pituitary is linked to that of the hypothalamus.
4. Describe the effects of TSH and ACTH. What hormones are produced?
5. What are the effects of the growth hormone of the pituitary? What is acromegaly and what causes it?

SUMMARY

The endocrine system is made up of glands and specialized groups of cells that produce hormones and secrete them directly into the bloodstream. Many homeostatic mechanisms involve hormones. Releasing factors from the hypothalamus stimulate the anterior lobe of the pituitary, which produces ACTH, TSH, three reproductive hormones, and a growth hormone. The posterior lobe of the pituitary stores and secretes the vasopressin, or ADH, and oxytocin that are produced by the hypothalamus. The adrenal medulla produces the “fight or flight” hormones—epinephrine and norepinephrine. ACTH from the pituitary stimulates the production of cortisol and aldosterone in the adrenal cortex.

REVIEW QUESTIONS

1. What are the effects of antidiuretic hormone, ADH? Where is it produced?
2. What hormones are produced in the adrenal glands? Where are these glands located?
3. What is the general function of the hormones produced in the adrenal medulla?
4. What are the six effects of epinephrine?
5. What are the general functions of the hormones secreted by the adrenal cortex? What causes these hormones to be produced?
6. What is the effect of thyroxine on the body? Can you state what conditions result from abnormal secretions of thyroxine?
7. What is a simple goiter? How has modern society all but eliminated this disorder?
8. What can result from abnormal secretions of parathormone? Where is this hormone produced?
9. What are the islets of Langerhans? What is produced there?
10. How are the two hormones of the question above related?

ANALYSIS AND APPLICATION

1. What could a diabetic person who has taken a slight overdose of insulin do to correct the imbalance?
2. What have you learned about hormone secretions that suggests how the conscious part of our brain might exert control over internal functions?

2. Epinephrine, norepinephrine, cortisol, and aldosterone. Above or near the kidneys.
3. They prepare the body for physical action.
4. (a) The heart beats faster and stronger. (b) Arterioles dilate or constrict. (c) Smooth muscle tissue is inhibited or stimulated. (d) The nerves of the spinal cord and the brain are stimulated. (e) The skeletal muscles have increased strength and endurance. (f) Metabolism and blood sugar level increase.
5. Cortisol increases the body's tolerance to stress. Aldosterone helps the nephrons control the homeostasis of Na^+ and K^+ . ACTH
6. It speeds up body metabolism, especially cellular respiration. Hyposecretion causes cretinism in children and myxedema in adults. Hypersecretion causes excessive activity.
7. An abnormally large growth of the thyroid caused by deficient iodine in the diet. Iodine is added to salt.
8. Hyposecretion causes the nervous system to be excitable, with muscular twitching and spasms. Hypersecretion causes poor bones and teeth. It is produced in the parathyroids.
9. Specialized hormone-producing tissue of the pancreas. Insulin and glucagon.
10. They have opposite effects.

ANSWERS TO ANALYSIS AND APPLICATION

1. Eat something with sugar, such as a candy bar, to increase the level of blood sugar.
2. The fact that powerful pituitary hormones are either stimulated or produced by the brain leads to speculation that the conscious part of our brain might somehow be linked to the activity of the hypothalamus.

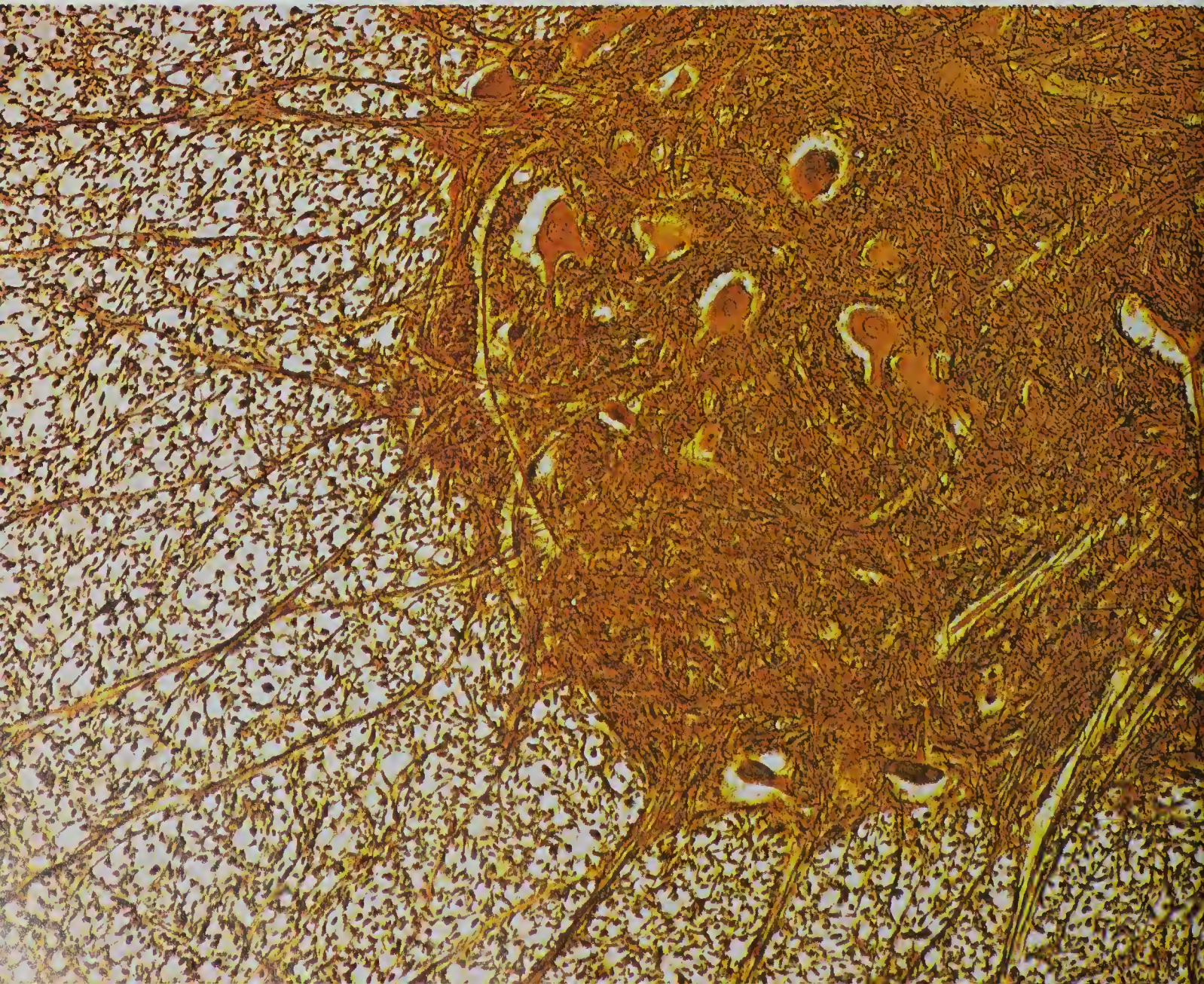
Investigations 56–57 from *Laboratory Investigations in Biology* can be done with this chapter.

37

Nerves and

OBJECTIVES

- To discuss the two roles of the nervous system
- To describe the unique structure of the neuron and how nerve impulses are transmitted
- To understand the nature of the synapse



- To appreciate that a nerve is a bundle of nerve fibers, or axons, with its protective sheath
- To know that the nervous system is made up of the central nervous system and the peripheral nervous system
- To describe the structure of the spinal cord and the spinal nerves, and the nature of the spinal reflex
- To understand the sympathetic and parasympathetic nerves
- To describe the main regions of the brain and their functions
- To explain the nature of mechanoreceptors, chemoreceptors, photoreceptors, thermoreceptors, and pain receptors
- To understand the sensory nature of the skin
- To appreciate that the olfactory and gustatory nerves are the main chemoreceptors of the body
- To discuss the nature of the eye as a photoreceptor
- To explain how sound vibrations are transmitted through the ear to the auditory nerves

the Brain

Neurons and Nerves

37-1 The basic functions The nervous system has two basic functions. It receives and interprets information from the environment and stimulates a response that enables the individual to respond to changes in the environment. The nervous system also coordinates all the internal systems of the body so that they function properly. The latter function is called **integration** (in tə grā'shən). The endocrine glands assist with integration. However, the nervous system has an advantage over the endocrine system. This advantage is speed. Information can be transmitted throughout the body much faster by the nervous system than by chemicals in the bloodstream.

37-2 The neuron The basic unit of the nervous system is the highly specialized nerve cell called a **neuron** (nūr'on). It has a cell body like that of most other cells. The neuron differs from other cells in having branched projections that extend out from the cell body. Some of the projections are called **dendrites** (den'drīts) and look like tree branches without leaves. The other type of projection is called an **axon** (ak'son). The axon is branched at the end.

Its specialized structure enables the neuron to transmit **nerve impulses**, which are electrical in nature. Impulses always travel in one direction through a neuron. They are received by the dendrites, transferred to the cell body, and then sent down the axon away from the cell body.

MAIN IDEA

The nervous system receives and interprets information from the environment and stimulates a proper response. It also integrates the internal systems of the body.

MAIN IDEA

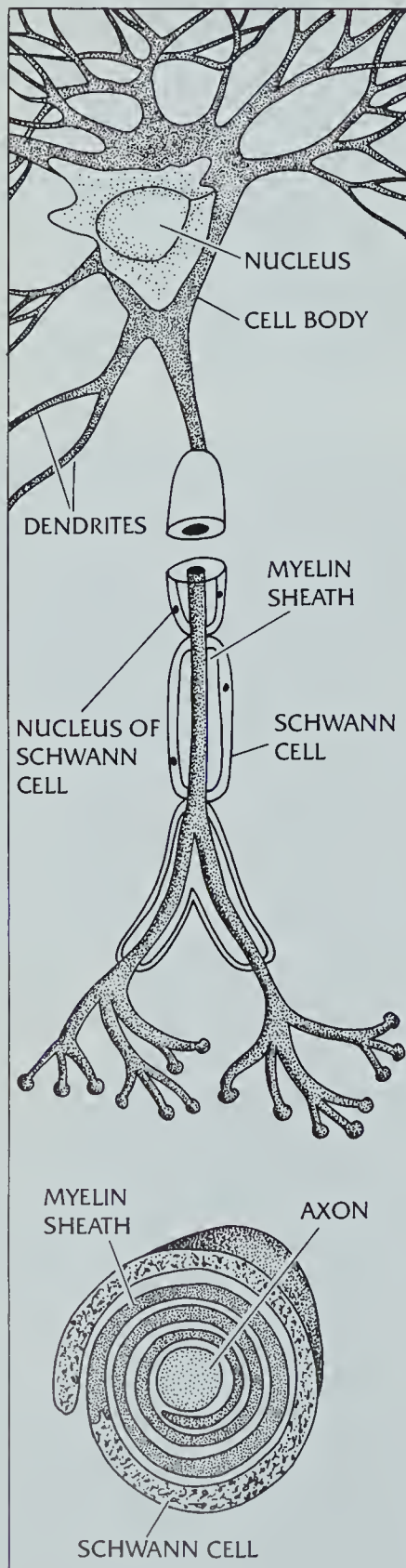
The specialized structure of the neuron allows it to transmit nerve impulses. Schwann cells make up myelin sheaths that often surround the axon of the neuron.

SCIENCE BACKGROUND

Nerve impulses are not flows of electrons, nor do the impulses travel anywhere near the speed of electric currents. These facts should be emphasized

FIGURE 37-1

The various structures of a typical neuron are identified in the figure below. An axon in cross section is shown at the bottom.



Many axons are surrounded by a white fatty material called **myelin** (mī'ə lin), which forms an outer sheath. The myelin sheath is made up of **Schwann cells** that are wrapped around the outside of the axon like a jelly roll. Between the Schwann cells there is a region where the axon is exposed to the tissue fluids. This region is called a **node** (nōd) **of Ranvier** (ron'vē ā).

37-3 The synapse To travel, nerve impulses must be passed from one neuron to another neuron. However, two adjacent neurons never directly touch each other. The impulses must pass across a gap between the neurons called a **synapse** (si naps'). On one side of the synapse there are the branched ends of the axon that is carrying a nerve impulse. At the branched ends of the axon there are usually little swellings that look like buttons. Inside the "buttons" are small vesicles that contain chemicals called **transmitters** (trans mit'ərs). One of the transmitters is the hormone **norepinephrine**. The other transmitter is a chemical called **acetylcholine** (as ə təl kō'lēn). A nerve impulse traveling down the axon stimulates the secretion of one of the transmitters. The transmitter bridges the

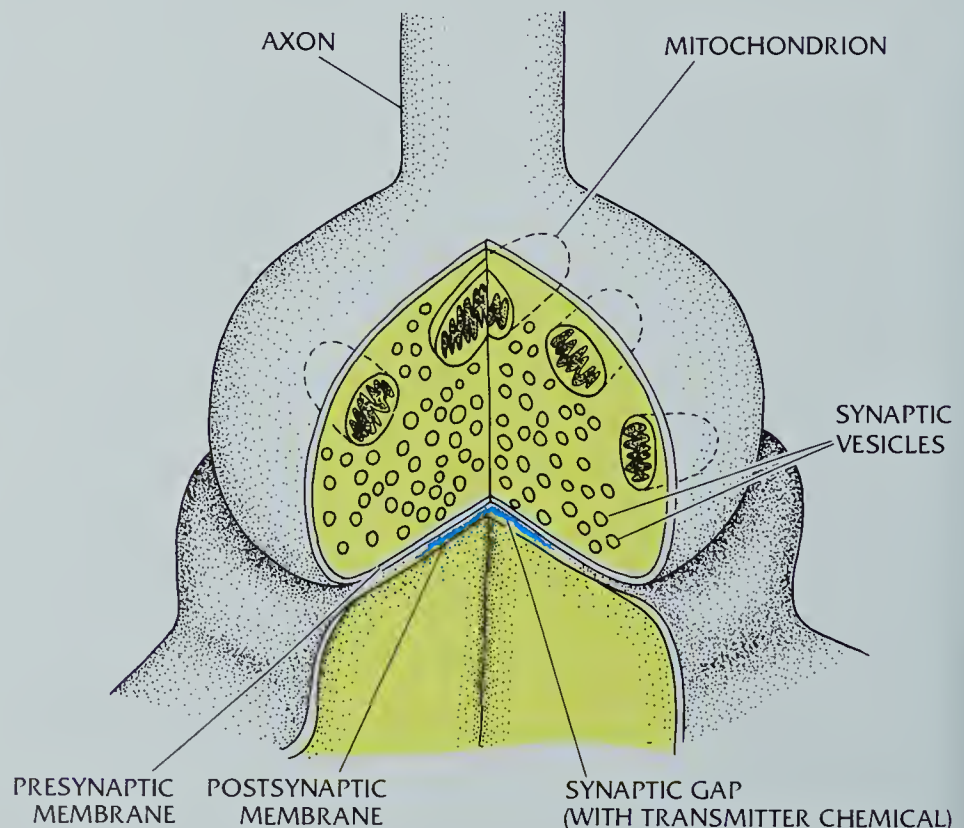


FIGURE 37-2 Chemical transmitters released by the axon cross the synaptic gap and stimulate dendrites on the next neuron.

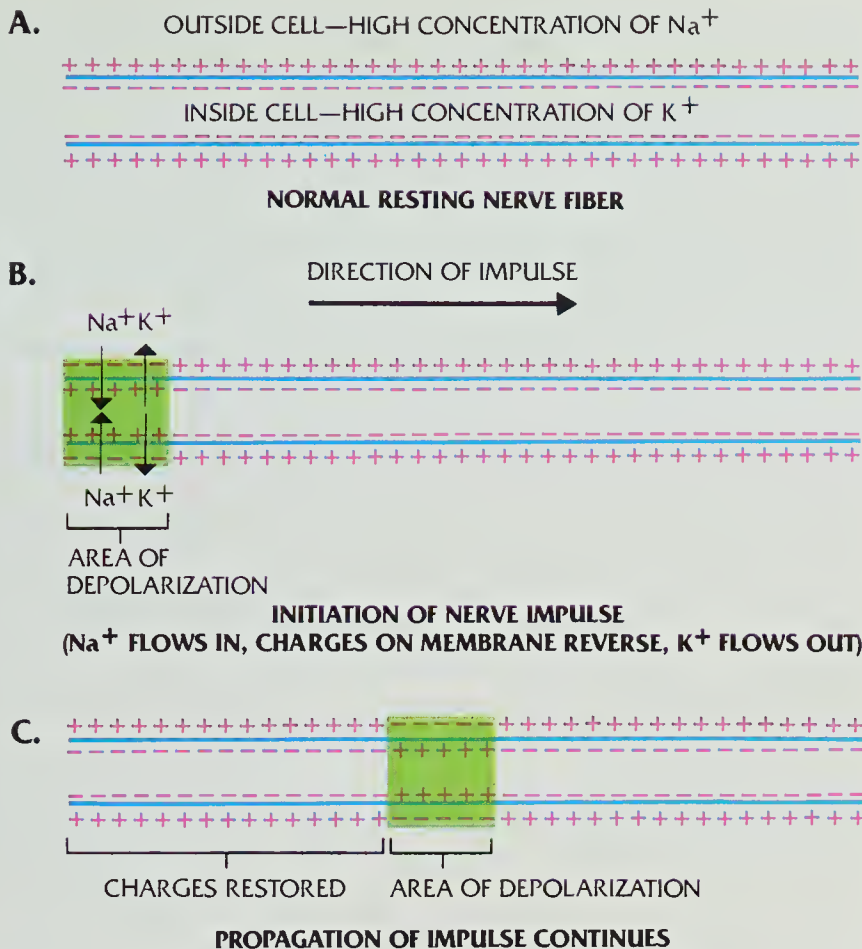


FIGURE 37-3 The passage of an impulse along the membrane of a neuron is illustrated in the diagram above.

synapse, forming a chemical linkage with the dendrites of the next neuron. The nerve impulse is transmitted across the synapse to the dendrites. It spreads to the cell body, then down another axon. At the synapse, immediately after transfer of the impulse, the transmitter is broken down by enzymes to clear the synapse for future impulses.

37-4 How nerve impulses travel Nerve impulses actually travel along the cell membrane of the neuron. A neuron that is not carrying a nerve impulse, called a resting neuron, has a membrane that is polarized. The inside of the membrane has a negative charge; the outside environment has a positive charge. When something stimulates a neuron, such as electricity, chemicals, or touch, a section of the membrane becomes depolarized. Then the inside of that section becomes positive. This reaction is very brief and the membrane quickly returns to its original polarized condition. However, when it was depolarized, it stimulated the adjacent membrane region, causing it to become depolarized. Thus there is a chain reaction down the length of the neuron, with one region of the membrane be-

SCIENCE BACKGROUND

Also near the vesicles are many mitochondria, which indicate that metabolism is active in that region. Several other transmitters have been discovered, some of which are stimulatory and some inhibitory.

Strychnine is a poison that decreases the resistance across the synapse.

MAIN IDEA

The nerve impulse is the continuous depolarization movement down the cell membranes of neurons. The depolarization is caused by ion flow across the membrane.

SCIENCE BACKGROUND

The potential difference across the membrane of a resting neuron is called the *resting potential*. When depolarization occurs, the electrical charge changes and this new potential is called the *action potential*.

Much of the research on nerve impulse transmission was done on the giant motor neurons of the squid, which are up to 1 mm in diameter—large enough to place electrode probes into them.

Researchers learned about the role of the membrane by pumping out the cytoplasm and replacing it with an ionic solution that duplicated the normal cell. These experimental axons performed like normal axons.

MAIN IDEA

Nerves are bundles of nerve fibers, or axons. The bundle, with its protective sheath, protects the individual axon from damage.

SCIENCE TERMS

integration
neuron
dendrites
axon
nerve impulses
myelin
Schwann cells
node of Ranvier
synapse
transmitters
norepinephrine
acetylcholine
nerve
nerve fibers

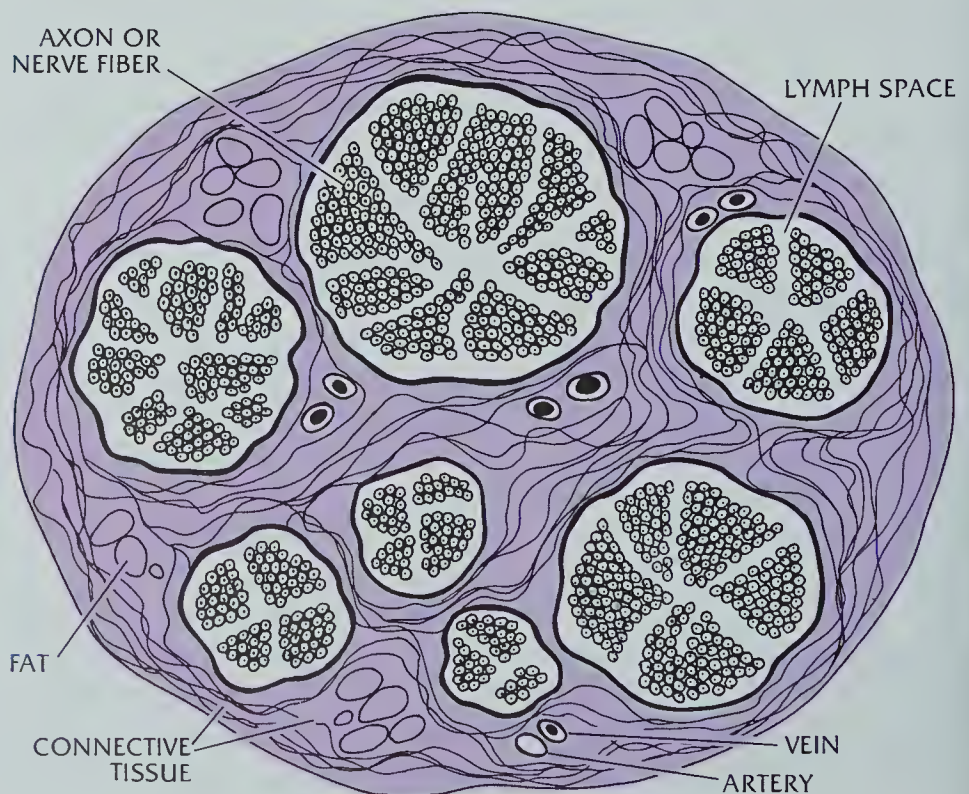
coming depolarized right after the other. *That depolarization movement down the cell membrane of the neuron is the nerve impulse.*

What causes the cell membrane to become depolarized? Research has shown that a resting neuron has a higher than normal concentration of sodium ions (Na^+) on the outside of the membrane. There is a higher than normal concentration of potassium ions (K^+) on the inside of the membrane. These abnormal concentrations are maintained by active transport. A “sodium pump” keeps Na^+ ions out of the neuron, and a “potassium pump” keeps K^+ ions inside the neuron. Whatever triggers the nerve impulse causes the membrane to be more permeable to Na^+ ions, and they flow in. The K^+ ions flow out. This flow of ions causes the depolarizing to occur. Shortly afterward the two “pumps” go back to work, pumping out sodium and pumping in potassium. This returns the membrane to its polarized, or resting, condition.

37-5 The nerve Some neurons are very long, mainly because of their long axons. For example, there are neurons with cell bodies in your toes and the ends of the

FIGURE 37-4

A nerve consists of bundles of axons or nerve fibers that are wrapped in a protective sheath.



axons in your spinal cord. You may wonder why a long delicate axon of extremely small diameter is not broken apart by your leg muscles. The axons survive because they are wrapped inside a protective sheath. A bundle of 50 to 500 axons will run along parallel to each other, wrapped in a sheath like a telephone cable. Such a bundle of axons is called a **nerve** (nèrv). The axons inside the nerve are called **nerve fibers**. Remember, each nerve fiber is an extension of the cytoplasm of a living cell, a neuron.

CHECK YOUR FACTS

1. What is the function of integration? Why is the nervous system superior to the endocrine glands in this function?
2. Describe the structure of a neuron.
3. In which direction does a nerve impulse travel in a neuron?
4. What are Schwann cells? What is a node of Ranvier?
5. What is a synapse? Can an electrical impulse cross a synapse?
6. Describe how a nerve impulse is transmitted across a synapse.
7. What happens to a transmitter after it has stimulated the dendrites of the next neuron? What two chemicals act as transmitters?

ANSWERS TO CHECK YOUR FACTS

1. The coordination of all the internal systems in the body. The nervous system is much faster and more precise.
2. The cell body has a cluster of branches called dendrites on one end. On the other end is a long single branch called the axon.
3. From dendrite to cell body to axon.
4. Schwann cells make up the protective myelin sheath of an axon. A node of Ranvier is a region between Schwann cells where an axon is exposed to tissue fluids.
5. The junction between two neurons. No.
6. The impulse in the axon stimulates the secretion of a transmitter that reacts chemically with the dendrites of the next neuron and causes a nerve impulse to be generated.
7. It is broken down by enzymes. Norepinephrine and acetylcholine.

Organization of the Nervous System

37-6 General organization The nervous system is made up of two subsystems. One is the **central nervous system**, which consists of the spinal cord and the brain. The other is the **peripheral** (pə rîf'ər əl) **nervous system**, which includes all the nerves that branch from the spinal cord and the brain.

All neurons, nerves, and nerve impulses are described in terms of their direction of movement. Generally two different names may be used for movement in each direction. **Afferent** (af'ər ənt) and **sensory** refer to movement toward the central nervous system. **Efferent** (ef'ər ənt) and **motor** refer to movement away from the central nervous system. For example, an afferent nerve or sensory nerve would be carrying impulses toward the spinal cord or the brain. An efferent nerve or motor nerve would be carrying impulses away from the spinal cord or the brain.

A unique type of neuron is the **interneuron** (in tər nūr'on), which passes an impulse from one neuron to an-

MAIN IDEA

The central nervous system consists of the spinal cord and the brain. All other nerves are of the peripheral nervous system. Impulses reaching an interneuron may be sent to several different neurons. Ganglia contain groups of nerve cell bodies and interneurons.

other. One interneuron may have dendrite connections with several other neurons. Hence an interneuron is somewhat like a small telephone switchboard. Impulses reaching an interneuron may be sent to several different neurons.

The great mass of nerve cell bodies and interneurons are in the brain and the spinal cord. However, there are many other groups of nerve cell bodies and interneurons outside the central nervous system. These groups are called **ganglia** (gang'glē ə) (sing. *ganglion*). Many of the neurons that control our internal organs have their cell bodies in ganglia.

MAIN IDEA

Spinal nerves extend out from between the protective vertebrae. Gray matter is made up of cell bodies; white matter is made up of dendrites and axons, many with myelin sheaths. The meninges protect the brain and the spinal cord.

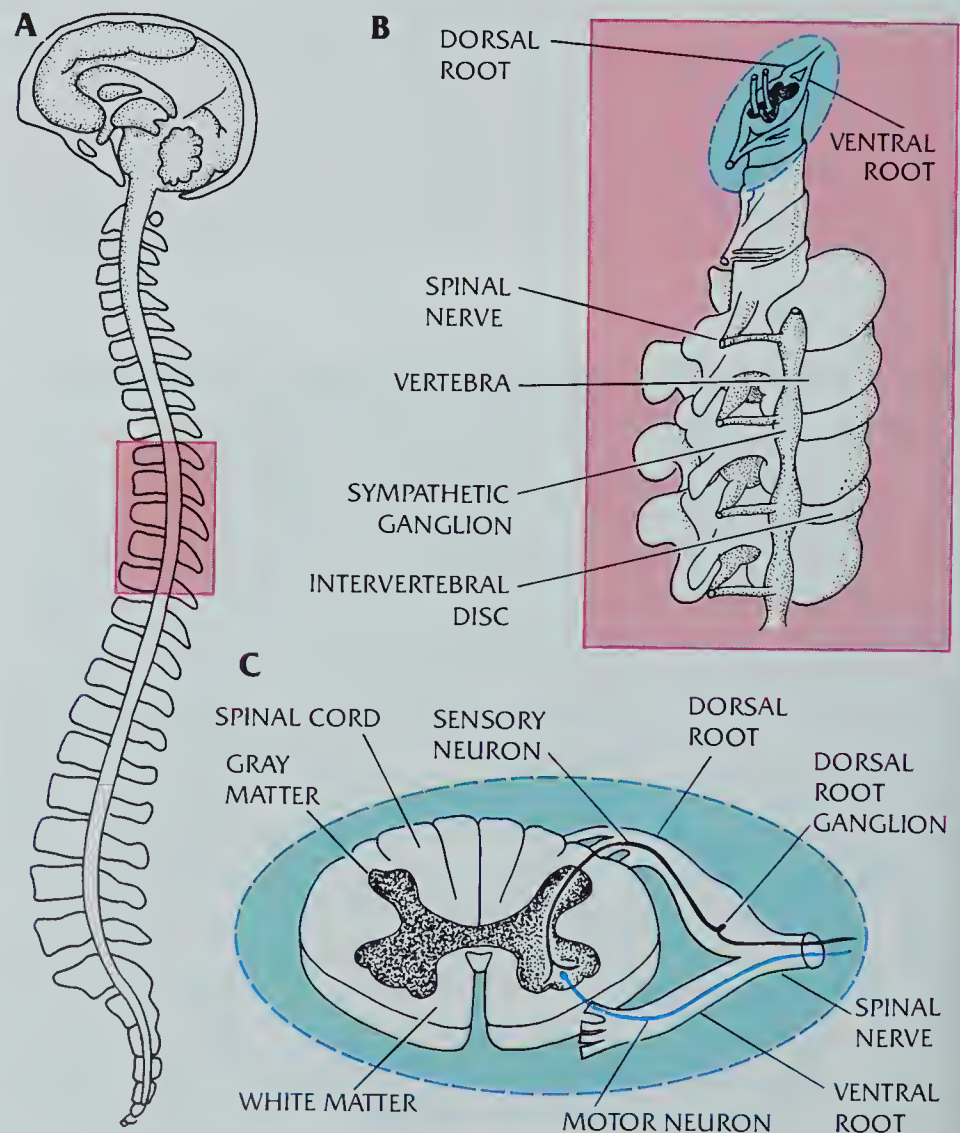
SCIENCE BACKGROUND

A teacher may prefer the following alternate terms: *dendrons* instead of *dendrites*, *medullary sheath* instead of *myelin sheath*, *soma* instead of *cell body*, and *motoneuron* instead of *motor neuron*. Also, some authorities restrict the definition of *motor neuron* to that of a neuron that carries nerve impulses to skeletal muscle, and use the term *autonomic neuron* to describe one that carries impulses to other effectors.

37-7 The spinal cord The spinal cord is a ropelike structure about the diameter of the little finger. It is sur-

FIGURE 37-5

The spinal cord is protected by the vertebral column. Spinal nerves are formed from dorsal and ventral roots of the spinal cord.



rounded by protective vertebrae, but it has 31 pairs of **spinal nerves** that extend out between the vertebrae. The spinal nerves control much of the body below the head.

A cross section of the spinal cord shows that it is made up of two kinds of nerve tissue. The center is made up of a butterfly-shaped region of **gray matter**. Gray matter consists of cell bodies of interneurons and motor neurons; dendrites; and synapses. The outer region, or **white matter**, is made up of bundles of axons and dendrites, many of which are covered with white myelin sheaths. The myelin sheaths are responsible for the name *white matter*. The axons of the white matter carry impulses up and down the spinal cord. Some impulses are going up to the brain. Others are coming from the brain, traveling down through the cord, and will go out to the body through the spinal nerves.

Each spinal nerve is formed from two roots that branch from the spinal cord. The **dorsal root** carries sensory impulses to the spinal cord. The **ventral root** carries motor impulses away from the cord.

Surrounding both the spinal cord and the brain are three membranes called the **meninges** (mə nin'jēz). Between the meninges is a fluid that helps to cushion the spinal cord and the brain and to protect them from injury. Sometimes these membranes become infected, causing a disease called meningitis.

37–8 A spinal reflex Sensory impulses from the body below the head come to the spinal cord, where they reach a synapse. That synapse may be with a motor neuron, which will send an impulse directly back to some part of the body. This is the simplest route, and it is called a **spinal reflex**.

An example of a spinal reflex is the **knee-jerk reflex**. If the leg is off the floor and relaxed, a tap just below the kneecap will cause the lower leg to rise. The tap stimulates a sensory neuron, which carries an impulse to the spinal cord. This sensory neuron synapses directly with a motor neuron that carries an impulse to an extensor muscle in the leg. The extensor muscle raises the leg.

Reflexes may be more complex and involve one or more interneurons. But they are simple enough that reactions to sensory information can be made quickly. Generally reflexes are protective. The knee-jerk reflex straightens out the leg if it starts to collapse. Another protective reflex will occur if you touch something hot. Your hand will draw away so fast that you will not have time to think about it.

SCIENCE BACKGROUND

To check student understanding of afferent and efferent spinal fibers, ask which spinal root would be injured if one lost all feeling in an arm but could still move it. (Ans: the dorsal root) Then ask which root would be injured if one could feel the arm but found it paralyzed. (Ans: the ventral root)

SCIENCE BACKGROUND

The knee-jerk reflex involves more than just one sensory and one motor neuron, although the two do elicit a response of the extensor muscle. The same sensory neuron also synapses with an interneuron, which in turn synapses with a motor neuron. The latter goes to the muscle antagonist, the flexor muscle, which causes the muscle to relax, thus making extension possible. The eye-pupil reflex is an example of a reflex that goes to the brain instead of to the spinal cord.

MAIN IDEA

Afferent and efferent nerve impulses involved in spinal reflexes follow the simplest neural pathways available. Their speed makes them ideal for protective responses.

SCIENCE BACKGROUND

The parasympathetic nerves include the vagus (tenth cranial), which branches to most of the abdominal organs, and the pelvic, which is formed from spinal nerves leaving three segments of the sacral vertebrae. They synapse close to the target organ. The sympathetic nerves primarily connect with the spinal cord and synapse in a chain of ganglia, called the sympathetic chain, just outside the spinal cord.

In a dramatic example of autonomic learning, rats were taught to control the constriction of arterioles to a point where different rates of blood flow would go to each ear.

MAIN IDEA

Sympathetic and parasympathetic autonomic nerves control the organs and internal functions. These nerves are normally without conscious control.

SCIENCE TERMS

central nervous system
peripheral nervous system
afferent
sensory
efferent
motor
interneuron
ganglia
spinal nerves
gray matter
white matter
meninges
spinal reflex
knee-jerk reflex
autonomic nerves
sympathetic nerve
parasympathetic nerve
psychosomatic

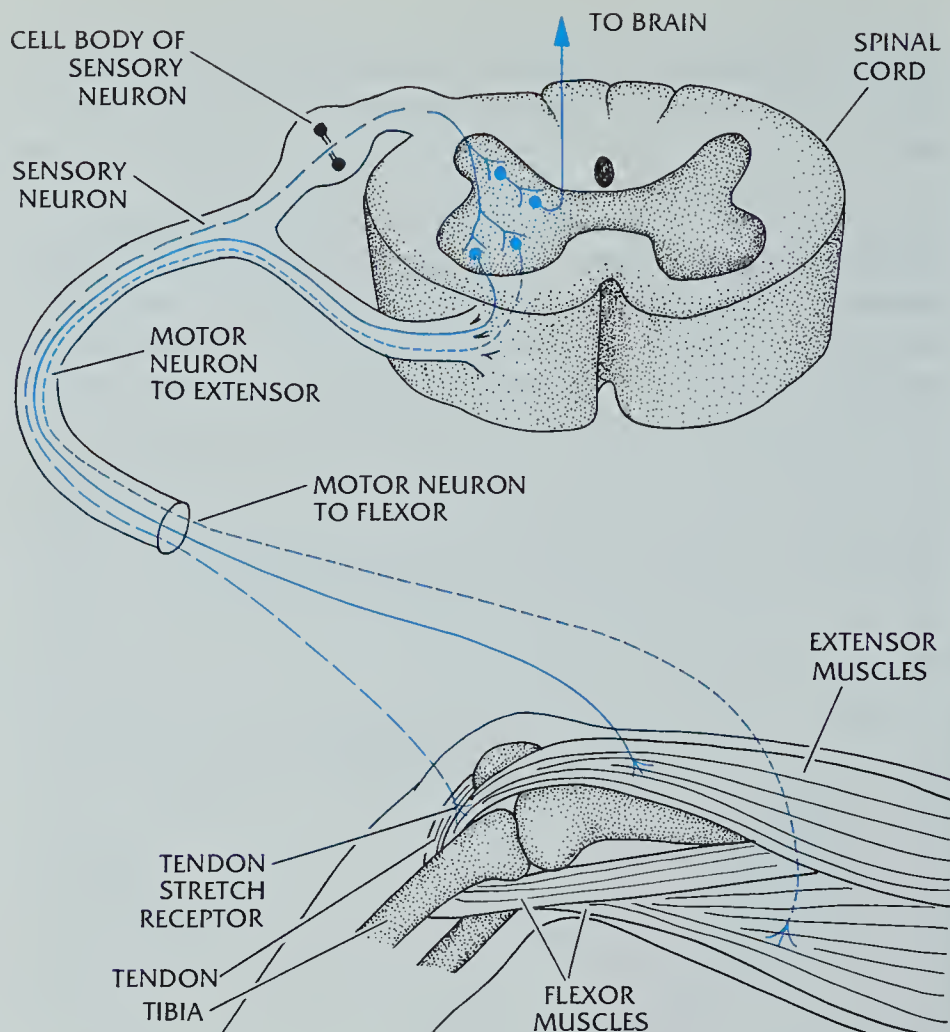


FIGURE 37-6

In a spinal reflex the nerve impulse passes along a sensory neuron to the spinal cord and then directly to a motor neuron.

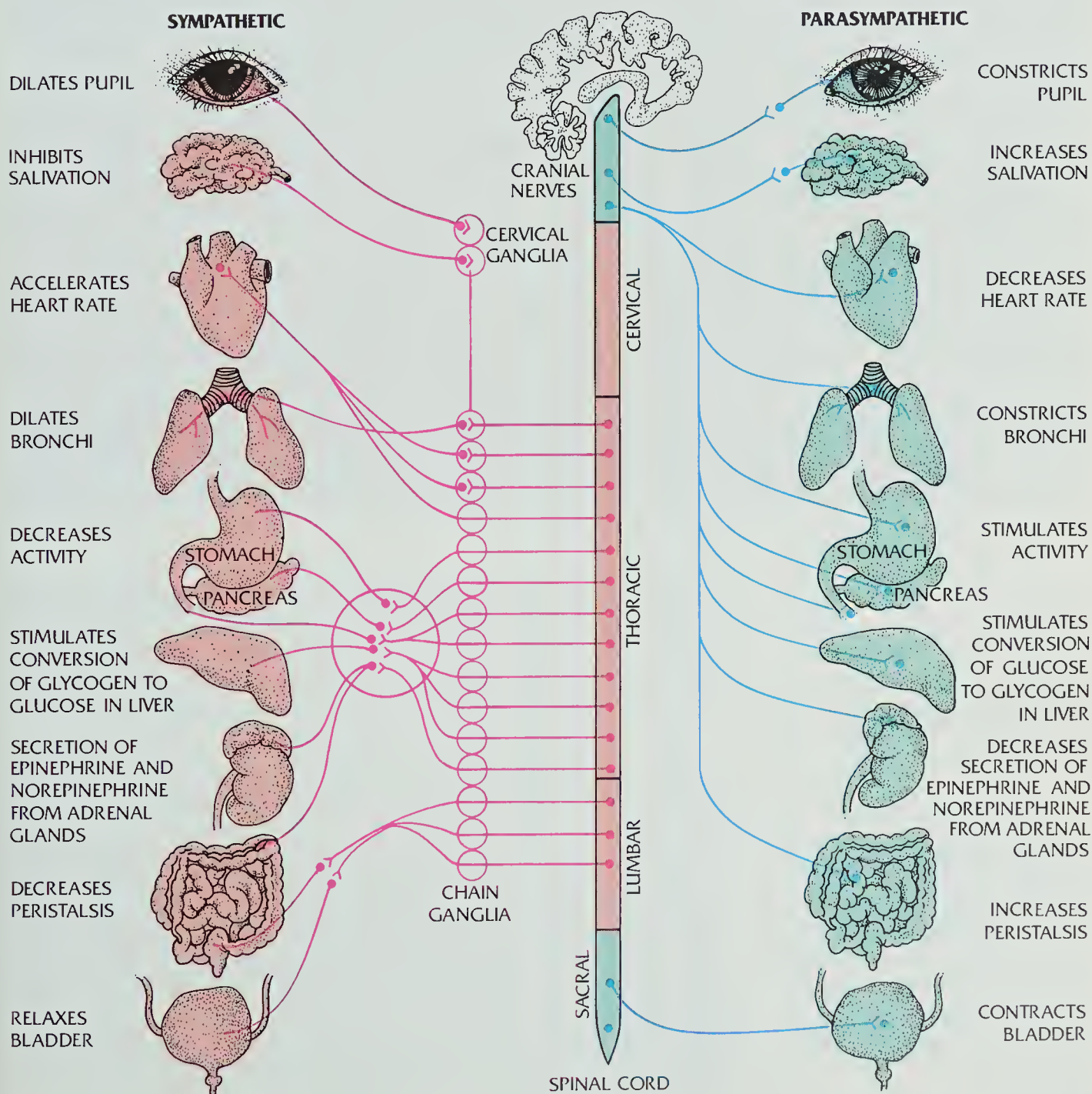
However, some reflexes can be overridden by our conscious thinking. For example, by holding the leg rigid while someone taps the knee, the knee-jerk reflex can be overridden and the leg will not move.

37-9 Autonomic nerves The term *autonomic* means “independent of control.” The **autonomic** (ô tã nom’ik) **nerves** are all the nerves that control functions that are mostly independent of our conscious control. These include such functions as respiration, excretion, digestion, heart beat, diameter of arterioles, internal reproductive functions, and release of hormones. Many of the cell bodies of autonomic neurons are in ganglia outside the brain and the spinal cord. The autonomic nerves are responsible for the second major function of the nervous system, which is the integration of the internal systems of the body.

Almost every organ and internal function is controlled by two opposing types of autonomic nerves. One type of autonomic nerve is called a **sympathetic** (sim pə thet'ik) **nerve**. The other type is called a **parasympathetic** (par ə sim pə thet'ik) **nerve**. We can use the heart to illustrate how these opposing types of nerves work. An impulse from a sympathetic nerve will cause the heart to beat more rapidly. But the heart is also linked to a parasympathetic nerve. An impulse from the parasympathetic nerve inhibits the heartbeat and causes it to slow down.

FIGURE 37-7

The subdivisions of the autonomic nervous system and their opposing actions are identified in the figure below.



ANSWERS TO CHECK YOUR FACTS

1. The central nervous system: the brain and the spinal cord. The peripheral nervous system: all nerves branching from the brain and the spinal cord.
2. Afferent and sensory. Efferent and motor.
3. In the brain, the spinal cord, and the ganglia.
4. The center is a butterfly-shaped region of gray matter that is composed of cell bodies, dendrites, and synapses. The outside is white matter and is composed of bundles of axons and dendrites, many covered by white myelin sheaths.
5. The dorsal root carries sensory, or afferent, impulses, and the ventral root carries motor, or efferent, impulses.
6. The three meninges have between them a fluid that serves as a cushion.

MAIN IDEA

The brain controls all body processes and interprets and responds to information from the receptors. Its regions are the brainstem, the cerebellum, and the cerebrum.

SCIENCE BACKGROUND

In technical discussions the brain is usually divided into regions based on its embryonic and evolutionary development. The basic terms *hindbrain*, *midbrain*, and *forebrain* are used.

Control from these opposing nerves keeps the heartbeat regulated and operating within a normal range. Control from the sympathetic and parasympathetic nerves keeps all other internal organs regulated.

Generally, autonomic nerves are called involuntary nerves. This means that we have no conscious control over them. However, it is possible for our conscious thinking to affect internal functions. Various experiments have proved that people can learn ways to control such things as heart rate and blood pressure. People can also think themselves into internal disorder. Such disorders result in headaches, digestive problems, or more serious diseases. Disorders or diseases that people think themselves into are called **psychosomatic** (sī kō sō mat'ik), which means "mind over body."

CHECK YOUR FACTS

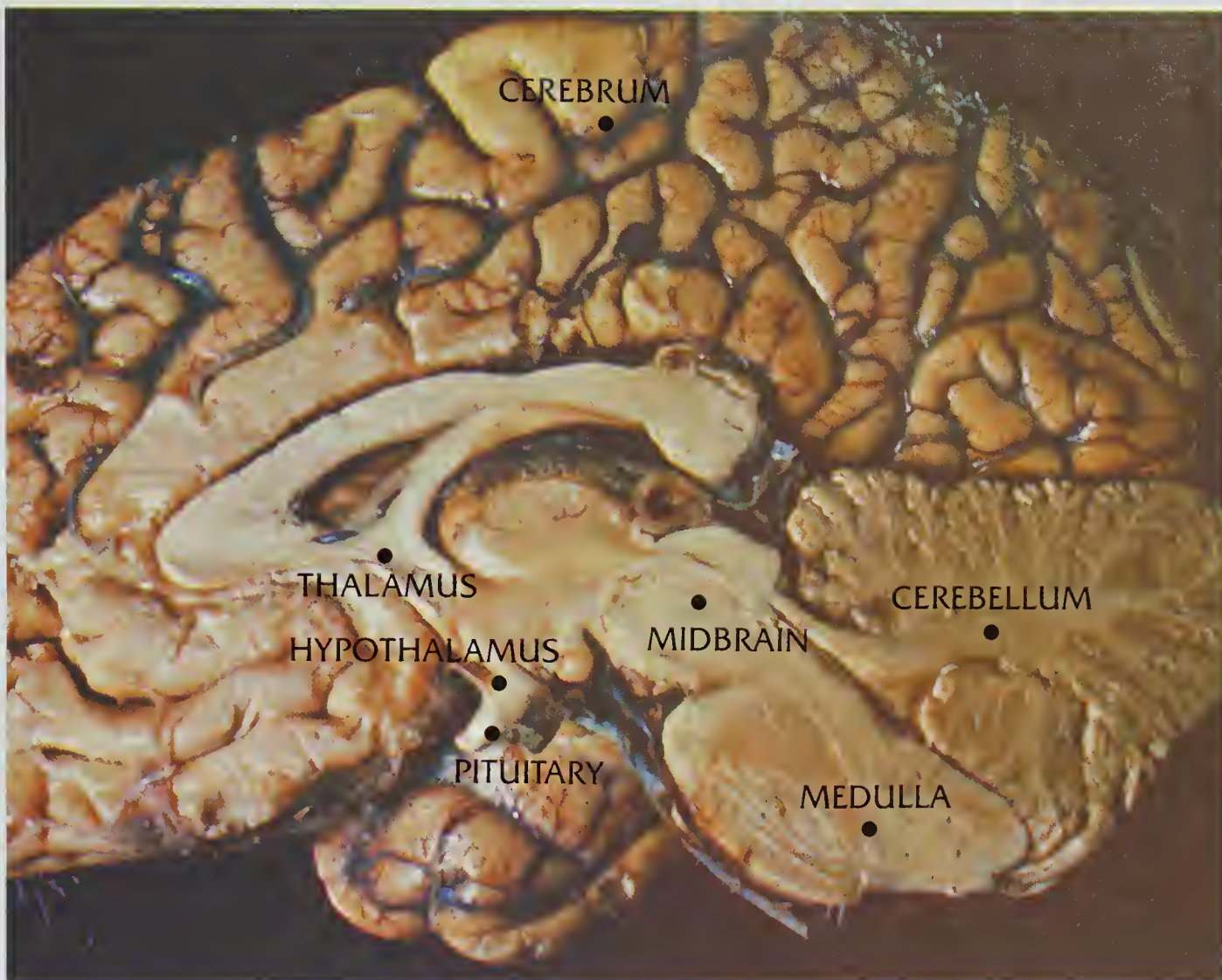
1. What are the two subsystems of the nervous system and what do they include?
2. What terms refer to movement toward the central nervous system? Away from it?
3. In what structures are nerve cell bodies found in groups?
4. Describe the cross section of the spinal cord. What do the two regions include?
5. What are the two roots of the spinal nerves for?
6. How are the brain and the spinal cord cushioned?

The Brain

37–10 General structure and function The human brain is the most highly organized, most complex organ in the body. Using this organ, humans have discovered and created enough knowledge to fill libraries and museums. But the human brain has failed in the search for one very important type of knowledge. It has not yet discovered how much of itself actually functions. Only in a general way do we understand the workings of the human brain.

The brain is divided into three basic regions. The first is the **brainstem**, the lower part of the brain that joins the spinal cord. The second region is the **cerebellum** (ser ə bel'əm), a baseball-sized region above the brainstem. The third region, the **cerebrum** (ser'ə brəm), is the largest part of the brain.

The brain has two main functions. It is the center that directly or indirectly controls all body processes. It also re-



The major areas of the human brain are identified in this photograph.

ceives, interprets, and responds to a wide variety of sensory information from outside the body. This second function relies on **receptors** (ri sep'tərs), which are specialized tissues or organs that respond to information. The information comes to the body in the form of touch, vibrations, chemicals, or light.

37-11 The brainstem The brainstem is often thought of as an extension of the spinal cord. The main region of the brainstem is the **medulla**. The medulla contains control centers for many vital processes of the body, including respiration and heart beat.

Another important part of the medulla is the **reticular formation**. This is a network of neurons that screens all the impulses on their way to the brain. It lets some through and even alerts parts of the brain that the impulses are coming. But the reticular formation blocks other impulses. For example, we do not normally

MAIN IDEA

The medulla controls many vital processes of the body. The reticular formation screens information before it reaches other parts of the brain.

feel the clothes that are on our body. Those touch impulses from our skin are kept out of our consciousness. But the reticular formation might let other forms of touch impulses through to the brain where they could be analyzed.

MAIN IDEA

The function of the cerebellum is mostly to coordinate muscular responses.

MAIN IDEA

The cortex of the cerebrum is the structure responsible for the superior intelligence of humans.

SCIENCE BACKGROUND

The cerebellum is the largest in proportion to brain size in fish, birds, and other animals whose activities involve movement in three planes. Students can better understand the nature of skeletal muscle coordination after they appreciate the complementary action of muscles (extensors, flexors, and so on) and their structure of individually innervated muscle fibers.

While the cerebellum coordinates the movements of skeletal muscles, many other sensory receptors and areas of the brain are involved in balance and coordination.

37-12 The cerebellum The cerebellum is a round and wrinkled region between the brainstem and the cerebrum. Its main function is to coordinate skeletal movements. However, it does not have complete control over body movements, as experiments on dogs have demonstrated. Dogs with their cerebellum removed still can move their body and walk. But their movements are not coordinated or smooth. Research has shown that movements are caused and controlled by impulses from the cerebrum.

37-13 The cerebrum The cerebrum is the largest part of the brain, making up about 80 percent of the total brain tissue. The unique part of the human cerebrum is its outer layer, or **cortex** (kôr'teks), which is a layer of gray matter 2 to 4 mm thick. The cortex has deep grooves and wrinkles that greatly increase its total area. No other ani-



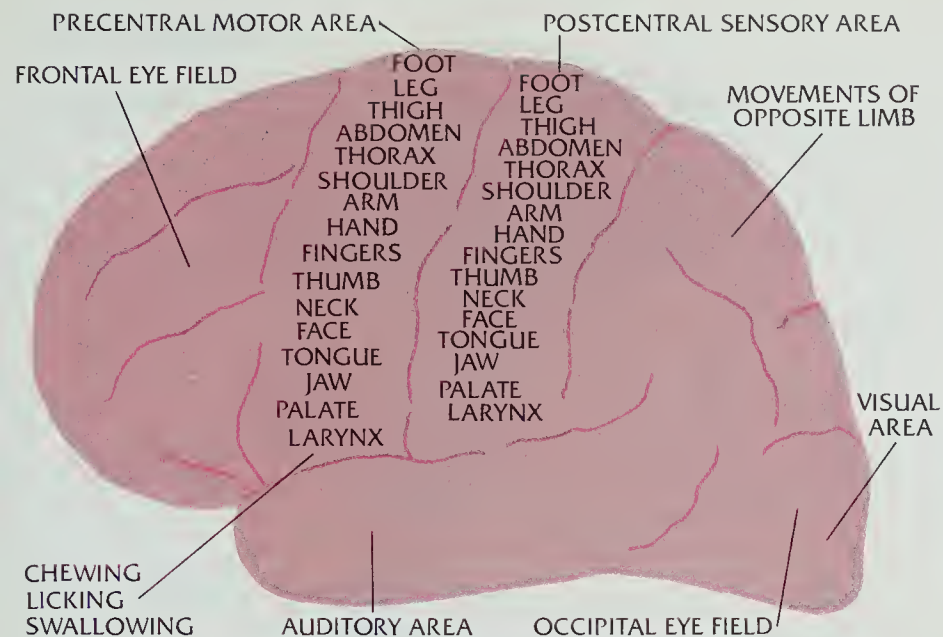


FIGURE 37-8 The sensory and motor regions of the cerebrum are identified.

mal has a cortex as well developed as that of the human. The cortex is the most outstanding biological difference between humans and other animals. Our cortex allows us to learn and to reason. It allows us to write poetry and make worn-out automobile engines run again. When someone mentions ice cream, we form a picture of ice cream in our mind. If someone says that the ice cream is strawberry-flavored, we see its red color. If we think harder, we can even “taste” the ice cream in our mind. All these activities are believed to be unique to the human cerebral cortex.

Experiments with animals and with humans who have suffered cerebral damage have enabled researchers to map the cerebral cortex. The mapping experiments have shown that there are sensory and motor regions in the cortex. Within each sensory and motor region there are specific body regions that are controlled by the cerebral cortex.

37-14 Other regions of the cerebrum At the base of the cerebrum is a pair of egg-shaped bodies made up of gray matter, called the **thalamus** (thal’ə mäs). The thalamus is like a relay station. It takes sensory nerve impulses (except smell) and relays them to the proper region of the cortex.

Beneath the thalamus is a small body of nerve tissue called the **hypothalamus** (hī pə thal’ə mäs). This region is mainly responsible for producing or stimulating secretion of pituitary hormones. The hypothalamus is the center

SCIENCE BACKGROUND

Also making up a large part of the cortex are *glial cells*, which are not neurons but are thought to nourish the neurons. They probably perform other and perhaps more profound functions that are yet to be discovered.

The cells of the brain, particularly the cortical cells, are extremely sensitive to oxygen deprivation. Four minutes is generally considered to be the maximum time the brain can function without oxygen before irreparable damage occurs.

MAIN IDEA

Other structures in the cerebrum are associated with emotions, short-term memory, and hormone production.

SCIENCE TERMS

brainstem
cerebellum
cerebrum
receptors
medulla
reticular formation
cortex
thalamus
hypothalamus
limbic system
hippocampus

SCIENCE BACKGROUND

For its size (only 4 g) the hypothalamus is a remarkably powerful bit of nerve tissue. Research into the activities of the hypothalamus, the limbic system, and the hippocampus is opening up exciting new frontiers where investigators are trying to unlock the secrets of mental diseases and learn more about physiology.

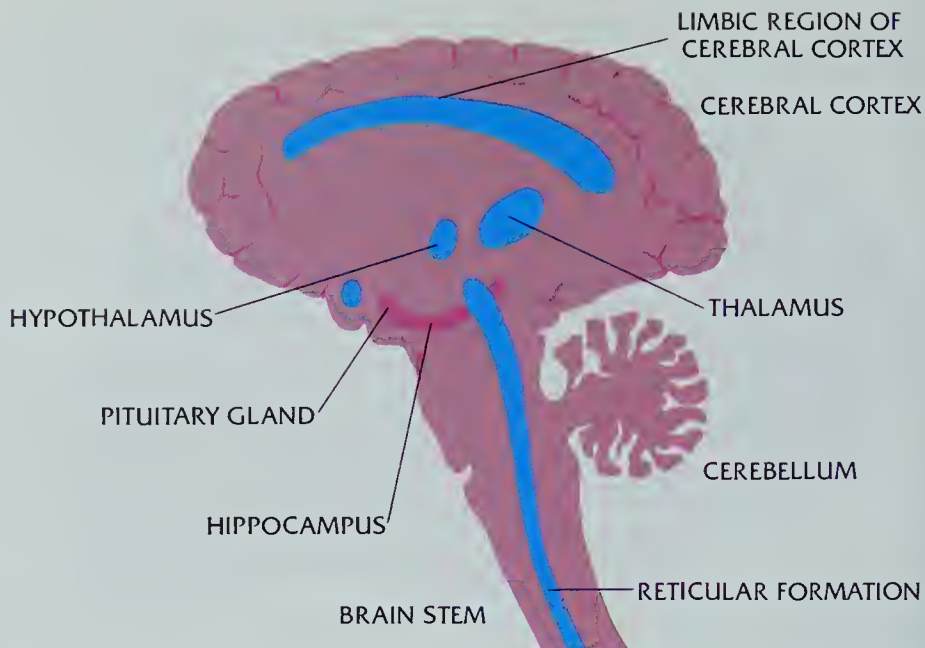


FIGURE 37-9 The internal regions and structures of the human brain are identified in this figure.

of control for such different body functions as thirst, pleasure, pain, anger, and the sex drive.

Another region that helps organize our emotions is the **limbic** (lim' bik) **system**, which is between the thalamus and the cerebral cortex. An electric probe can be stimulated in one section of a cat's limbic system, and the cat will claw and scream with rage. But if the electric probe is touched to another region, the same cat will purr and become affectionate.

A section of the limbic system, called the **hippocampus** (hip ə kam' pəs), seems to have a unique role in memory. It seems to be the section where our short-term memory is stored. Short-term memory is the type that stores a telephone number long enough for us to dial the number. Ten minutes later that number is forgotten, but we are ready to learn a new one for a short time.

ANSWERS TO CHECK YOUR FACTS

1. Brainstem, cerebellum, and cerebrum.
2. It controls directly or indirectly all body processes. It receives, interprets, and responds to stimuli from the receptors.
3. The medulla. It controls many processes, including respiration and heartbeat.
4. It is part of the medulla. It screens information destined for other parts of the brain and lets through only the significant impulses.
5. To coordinate skeletal movements.
6. About 80 percent. The cortex.

CHECK YOUR FACTS

1. What are the three basic regions of the brain?
2. What are the two major functions of the brain?
3. What is the main region of the brainstem? What influence does this region have on the body?
4. Where is the reticular formation located? What is its function?
5. What is the main function of the cerebellum?
6. How much of the brain does the cerebrum comprise? What is its most significant substructure?

Receptors

37-15 Types of receptors A sensory receptor, often called a **receptor** (ri sep'tər), is an organ or tissue that can be stimulated to send sensory impulses to the central nervous system. Receptors range in complexity from such complex organs as the eye and ear to scattered ends of nerve fibers in the skin.

There are five general types of receptors in the human body. One type, the **mechanoreceptor**, responds to mechanical stimulation, such as pressure, stretching, or vibration. There are mechanoreceptors all over the skin and through the interior of the body. A highly specialized mechanoreceptor is the ear, which responds to air vibrations, or sound.

The second type of receptor is the **chemoreceptor**, which responds to the stimulation of chemicals. Both the tongue and the nasal cavities have chemoreceptors that respond to chemicals that we sense as taste and odor.

A third type of receptor is the **photoreceptor**. The photoreceptor responds to certain wavelengths of electromagnetic radiation. The human eye is a photoreceptor that responds to the electromagnetic radiation that we call visible light. Other types of light—ultraviolet light and infrared light—cannot be detected by the human eye.

The other two types of receptors are **thermoreceptors** (thər mō ri sep'tərs) and **pain receptors**. Thermoreceptors are mostly in the skin and just inside the openings of the digestive tract. Some detect heat, while others detect cold. Pain receptors are found in many parts of the body and allow a person to know when some part of the body is injured.

37-16 Receptors in the skin Three of the five different types of receptors can be found in the skin. The skin can detect heat or cold, touch or pressure, and pain. The distribution of these receptors varies, and the actual location on the skin is called a sensory spot. For example, the palm side of a fingertip contains about 60 spots where pain can be detected and 100 touch spots within 1 cm². The back of the same finger has about 100 pain spots but only 9 touch spots. Obviously the skin is one of the body's major sense organs.

37-17 Organs for chemoreception The nasal cavities and the surface of the tongue are the major organs for chemoreception in the body. In the nasal cavities the **olfactory** (ol fak'tər ē) **nerves** have endings in the

MAIN IDEA

Humans have mechanoreceptors, chemoreceptors, photoreceptors, thermoreceptors, and pain receptors.

SCIENCE BACKGROUND

Technically receptors are transducers because they convert one form of energy to another. Whatever the initial energy form (pressure, chemical stimulation, and so on), the receptor is depolarized, an action potential is initiated, and the nerve impulse is on its way to the central nervous system. The exact mechanism for the depolarization of each type of receptor is not understood. It is known that deformation of the receptor membrane in mechanoreceptors causes a change in the size of the membrane pore. Chemicals probably also change the size of the membrane pores.

Receptors have been classified in other ways. Some classifications divide them into exteroceptors (outside receptors) and interoceptors (inside receptors).

MAIN IDEA

The skin can detect heat or cold, pressure or touch, and pain. Distribution of sensory spots varies.

MAIN IDEA

Olfactory nerves in the nasal cavities and gustatory nerves in the taste buds are the main chemoreceptors of the body.

SCIENCE BACKGROUND

The sense of smell seems to perform several functions for humans, but it is much less important than in most other animals. It helps create an appetite and stimulates the flow of digestive juices.

Another taste often recognized is a metallic taste. Taste buds have a short life span and are constantly being regenerated. To demonstrate that food must be dissolved to be tasted, dry off the tongue with a clean towel, then place a cube of sugar on the tongue. It will not be tasted until some of it has dissolved.

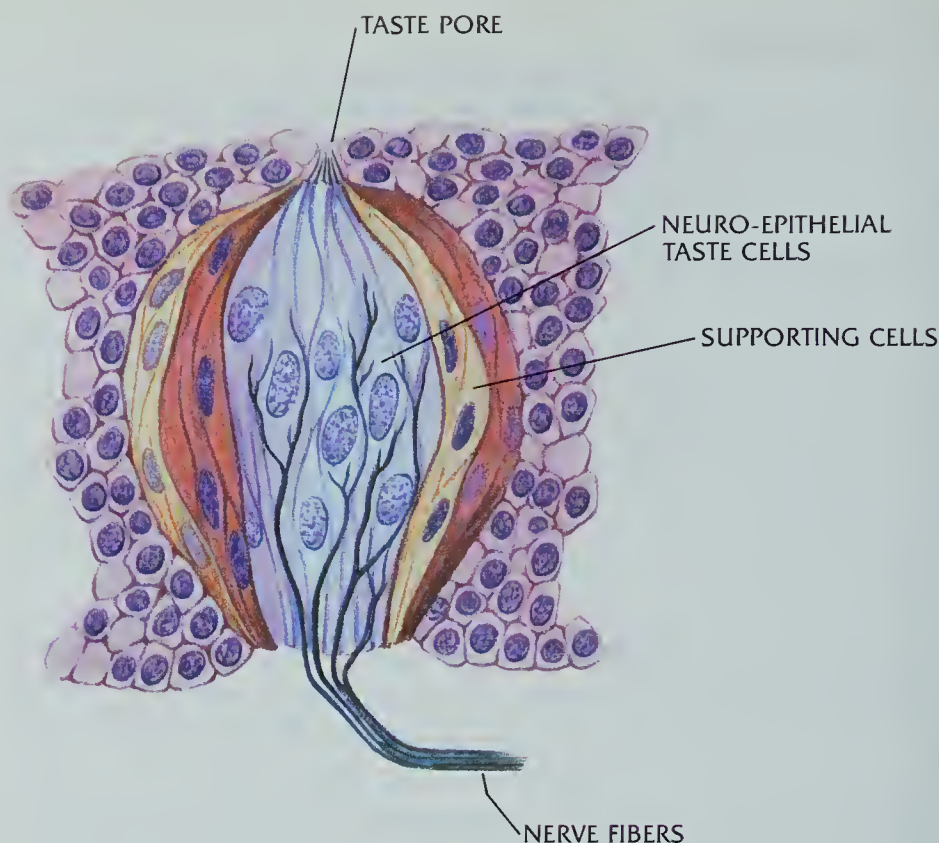


FIGURE 37-10

Taste buds are located on the surface of the tongue. Dissolved foods stimulate hairlike extensions of the taste cells.

mucous membrane. The olfactory nerves are one of 12 pairs of cranial nerves, or nerves from the brain. Chemicals in the air strike the nerve endings in the mucous membrane and trigger impulses that travel through the olfactory nerves. In the brain the odors are interpreted.

The tip and edges of the tongue are covered with specialized groups of cells called **taste buds**. Some of the cells have hairlike extensions from depressions in the taste buds. Dissolved foods come in contact with those hairs and stimulate the end fibers of **gustatory** (gus'tə tōr ē) **nerves**. The gustatory nerves, or nerves of taste, travel through three different pairs of cranial nerves. Food that is not in solution cannot be tasted. Also the sense of smell helps in tasting. Raw onion tastes somewhat like raw potato if you hold your nose while you chew the onion.

Tastes are usually classified into four categories: sweet, sour, salt, and bitter. However, the four tastes are not equally detected all over the tongue. Sweet and salt tastes are best tasted on the tip of the tongue. Sour tastes are strongest on the sides of the tongue. Bitter tastes are more strongly detected near the back of the tongue.

37-18 Our photoreceptors: the eyes To understand the function of the human eye, one must first understand its structure. The human eye is ball-shaped and about 2.5 cm in diameter. It is composed of three layers, or coats. The outer coat, the **sclera** (sklir'ə) or sclerotic coat, is the white part of the eye that we can see. The sclera is a tough layer of connective tissue that protects all the other layers. However, the very front part of the sclera differs in structure and function. It is transparent and is called the **cornea** (kôr'nē ə). The cornea allows light to pass through it into the eyeball.

The second or middle coat is the **choroid** (kôr'oid). It is pigmented and has many capillaries. At the front of the eye it is usually colored brown, gray, green, or blue and is called the **iris** (ī'ris). The iris has a round opening, the **pupil** (pyü'pəl). Small muscles in the iris can change the diameter of the pupil and quickly adjust the amount of light entering the eyeball.

The innermost coat is the **retina** (ret'ə nə), which has the nerve endings of the **optic** (op'tik) **nerve**, one of the cranial nerves. The retina is like the film in a camera. Images focused upon the retina are recorded in the brain, just as the camera film records visual images.

The **crystalline** (kris'tə lin) **lens**, usually called the lens, is transparent and separates the eye into two chambers. The anterior chamber is filled with a liquid called

MAIN IDEA

Optic nerves in the retina are stimulated by images that pass through the portion of the pupil not covered by the iris. The crystalline lens focuses the image. Rods and cones in the retina adjust to light intensity. Cones detect color.

SCIENCE BACKGROUND

Glaucoma, a disease that causes about one third of all blindness, is caused by increased humor pressure in the eyeball. The pressure squeezes the blood vessels and shuts off the blood supply to the retina. If detected early, this pressure can be relieved by medication or surgery, and blindness can be prevented.

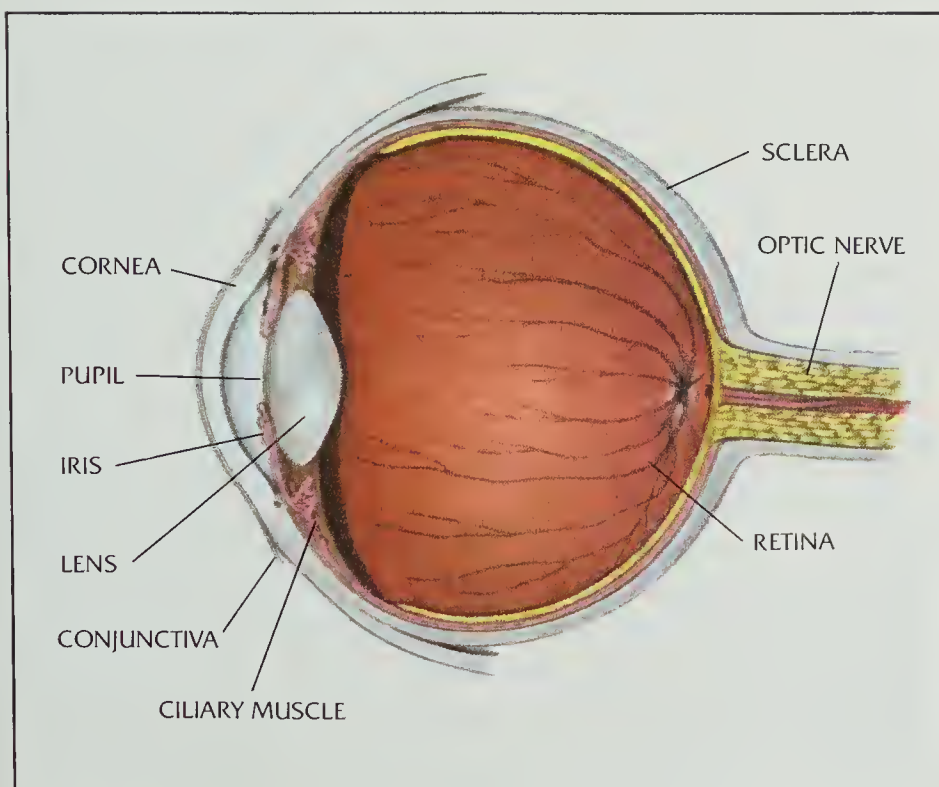


FIGURE 37-11

The structure of the human eye is shown in this illustration.

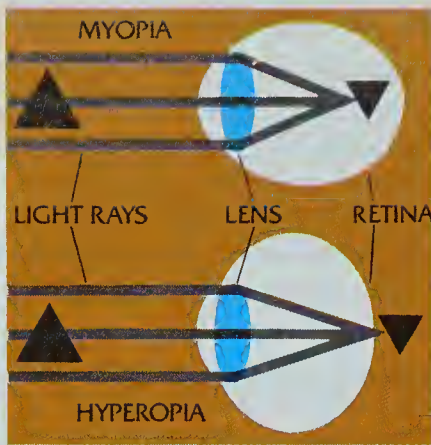


FIGURE 37-12

In nearsightedness, light focuses in front of the retina. In farsightedness, light focuses behind the retina.

MAIN IDEA

Sound vibrations that stimulate the tympanic membrane are amplified by the bones in the middle ear. The stirrup causes vibrations of the liquid in the cochlea, which causes sensory hairs to send nerve impulses to the brain. Semicircular canals in the inner ear enable the body to remain balanced.

SCIENCE BACKGROUND

The auditory nerve is the eighth cranial nerve. The auditory canal is also called the *external auditory meatus*. The name for earwax is *cerumen*. Hairs and sebaceous glands also are in the auditory canal. The three small bones are called the auditory *ossicles*.

aqueous (ā'kwē əs) **humor**. The chamber behind the lens is filled with another fluid, the **vitreous** (vit'rē əs) **humor**. The lens is flexible and is connected to muscles. The movement of the muscles can cause the lens to become rounder or flatter. This changes the focus of the lens. Hold a pen at arm's length, but focus your eyes on some object several meters away. The pen will be visible but blurred. Now look at the pen, and the lens will focus on it, leaving the object in the background blurred. The change in focus is caused by the lens changing its thickness. (A camera works much the same way our eye does; however, focus is changed by moving the lens back and forth.)

The retina has two types of highly modified cells called rods and cones. The **rods** are used for vision in dim light and cannot detect color. Notice at dusk or dawn that bright-colored flowers are merely a shade of gray. The **cones** are for daylight vision, and they do detect color.

You have probably noticed that it is difficult to see in dim light right after being in normal light as when entering a movie theatre in the afternoon. This is because the rods contain a pigment that is bleached out in bright light. Before the rods can function, this pigment has to be replaced. The pigment replacement is what is occurring as your eyes become "used to the dark."

37-19 Our main mechanoreceptors: the ears

The ears detect sound, which is the vibration of air. The ear itself is divided into three parts, each with a unique structure and function. The **external ear** consists of three parts. The **auricle** (ô'r'ə kəl), the part that you see and call the ear, collects some sound waves. However, it is not known exactly how much it aids in the hearing process. The second part of the external ear is the **auditory** (ô'də tôr ē) **canal**, which leads to the eardrum, or **tympanic** (tim pan'ik) **membrane**. Sound travels down the auditory canal and causes the tympanic membrane to vibrate. Also in the auditory canal are glands that produce earwax, which helps to prevent the growth of microorganisms.

Just beyond the tympanic membrane is the **middle ear**. It is a cavity in the bone of the skull in which three tiny little bones are linked together. The bones are called the **hammer**, **anvil** (an'vəl), and **stirrup** (stêr'əp). The hammer is linked to the tympanic membrane, and vibrations spread through the three bones. However, the strength of the vibrations is magnified about 22 times as they travel through the three bones. Also opening into the middle ear is a tube that links it with the upper pharynx.

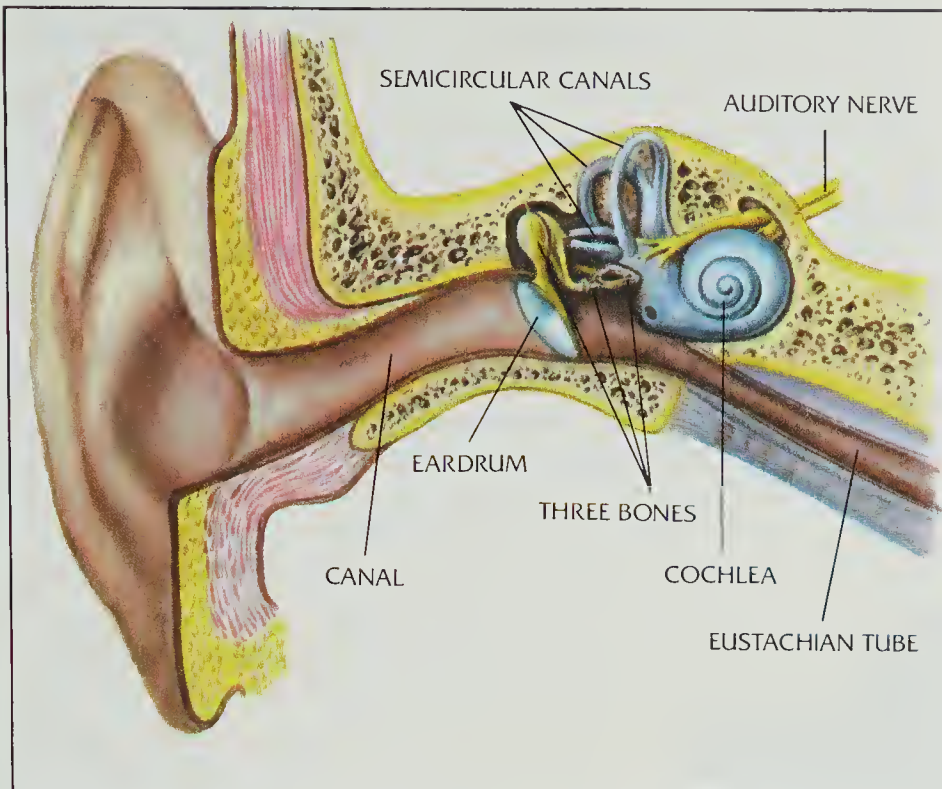


FIGURE 37-13 The structures of the ear are involved in the detection of sounds and in the maintenance of body equilibrium.

This tube, called the **Eustachian** (yü stā'kē ən) **tube**, allows the air pressure in the middle ear to remain equal to that on the outside of the tympanic membrane. Unfortunately the Eustachian tube also can allow disease bacteria to get into the middle ear. Such bacteria can cause troublesome infections and earaches.

The third part of the ear is the **inner ear**, which is a winding set of cavities in the skull bone. One of the winding cavities is called the **cochlea** (kok'lē ə) and looks like a snail shell. The cochlea contains liquid-filled tubes, some of which are lined with sensory hairs. The stirrup, the last of the three bones in the middle ear, vibrates against a membrane in the inner ear. The vibrations of this membrane cause movement of the liquid in the cochlea. The sensory hairs respond according to the different frequencies of vibration, and nerve impulses are sent out through the **auditory nerve** to the brain.

Also in the inner ear are three liquid-filled **semicircular** (sem ē sēr' kyə lər) **canals**, which have nothing to do with the sense of hearing. The three semicircular canals are arranged at right angles to each other. Also, they are lined with sensory hairs. As the head moves, the hairs are stimulated and impulses are sent to the brain. The in-

SCIENCE TERMS

receptor
 mechanoreceptor
 chemoreceptor
 photoreceptor
 thermoreceptors
 pain receptors
 olfactory nerves
 taste buds
 gustatory nerves
 sclera
 cornea
 choroid
 iris
 pupil
 retina
 optic nerve
 crystalline lens
 aqueous humor
 vitreous humor
 rods
 cones
 external ear
 auricle
 auditory canal
 tympanic membrane
 middle ear
 hammer
 anvil
 stirrup
 Eustachian tube
 inner ear
 cochlea
 auditory nerve
 semicircular canals
 equilibrium

ANSWERS TO CHECK YOUR FACTS

1. An organ or tissue that can be stimulated to send sensory impulses.
2. Mechanoreceptors, chemoreceptors, photoreceptors, thermoreceptors, pain receptors.
3. Mechanoreceptors, thermoreceptors, pain receptors. No.
4. Sweet, sour, salt, bitter.

formation from the semicircular canals allows the brain to send out motor impulses to the muscles. In turn, this information allows the muscles to keep our body balance, or **equilibrium** (ē kwə lib'rē əm). Motion sickness and dizziness from an exercise such as whirling are caused by abnormal responses of the semicircular canals to this strange motion. Training for a period of time—as by a sailor on a ship or an ice skater doing routine whirls—can condition the canals and prevent motion sickness or dizziness.

The structure of the brain in representatives of the five classes of vertebrates—fish, amphibian, reptile, bird, and mammal—is shown below.

1.



2.



3.



5.



4.



CHECK YOUR FACTS

1. What is a receptor?
2. What are the five general types of receptors found in humans?
3. What receptors are found in the skin? Are they evenly distributed?
4. What are the four categories of taste?

SUMMARY

The nervous system receives and interprets information from the environment and stimulates a proper response. The structure of the neuron enables it to transmit electrical nerve impulses from the dendrites through the cell body and then through the axon. Axons are protected by forming bundles called nerves. The brain and spinal cord are called the central nervous system. The peripheral nervous system includes all other nerves.

REVIEW QUESTIONS

1. Describe the structural unit of the nervous system.
2. List four ways that nervous tissue is protected.
3. Trace the path of the nerve impulse in the knee-jerk reflex.
4. What are autonomic nerves? How do they control the heart rate?
5. Name five parts of the cerebrum and a function of each.
6. Describe the processes that allow an electrical impulse to travel from one neuron to the next.
7. What mechanism helps keep infectious organisms from growing in the ear? How do most ear infections occur?
8. What three structures lie between the tympanic membrane and the membrane of the inner ear? What function do they serve?
9. What are the three coats of the eye? How is the eye divided into two chambers?
10. How does the crystalline lens focus an image?

ANALYSIS AND APPLICATION

1. How does the brain learn that the liquid you have just poured into your mouth is unsweetened lemon juice?
2. Some of the sounds that we hear are not directly transmitted from the outer ear through the tympanic membrane. Can you name some?

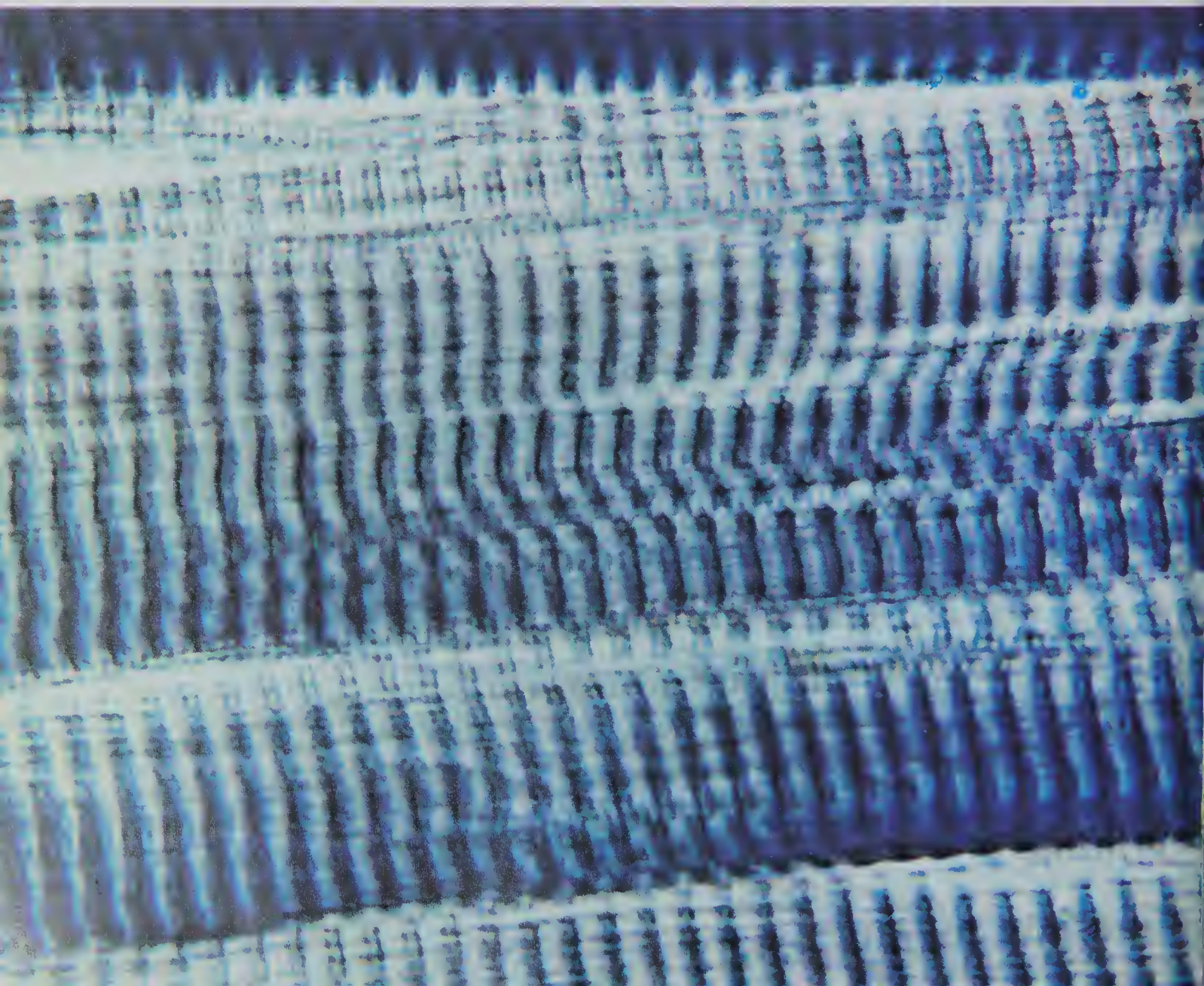
ANSWER TO REVIEW QUESTIONS

1. The neuron has a cell body with a long single branch on one end (the axon) and several shorter branches on the other end (dendrites).
2. Myelin sheaths, vertebrae, the skull, and the meninges.
3. A sensory neuron carries the impulse to the spinal cord, where it synapses directly with a motor neuron that carries an impulse to a muscle in the leg.
4. See section 37-9.
5. See sections 37-13 and 37-14.
6. See section 37-3.
7. Glands in the auditory canal produce a wax that prevents growth in the external ear. Through the Eustachian tube.
8. The hammer, anvil, and stirrup bones. They magnify the strength of the vibrations.
9. The sclera, the choroid, and the retina. The crystalline lens divides the eye into chambers.
10. With muscles that make the lens thicker or thinner.

ANSWERS TO ANALYSIS AND APPLICATION

1. The lemon juice stimulated some gustatory nerves, and an impulse traveled through cranial nerves to the brain. In the nose, vapors from the liquid stimulated the endings of the olfactory nerves. Impulses traveled up these nerves to the brain. The cortex of the brain interpreted both groups of impulses.
2. Sounds of foods such as celery and radishes being chewed travel through the skull. Our own voice is heard primarily through the skull.

38 *Skeletal and Muscular*



OBJECTIVES

- To understand the nature of compact and spongy bone
- To appreciate the role of

cartilage in the child and in the adult

- To explain the role of collagen fibers in holding the parts of the human body together
- To describe the basic functions of the skeleton
- To describe the three basic types of joints and how they function
- To understand the basic nature of skeletal muscle tissue and how it functions
- To understand how muscles do work

Systems

The Skeletal System

38-1 Bone tissue The skeletal system is made up of three kinds of tissues: bone, cartilage, and connective tissue.

Bone tissue is different from most other tissues. Bone is the hardest of all the tissues. Bone consists of more cell products than cells. Cells make bone by secreting calcium and phosphorous compounds that harden into a mineral. The photograph shows a cross section of bone as seen through a light microscope. In the preparation of the bone cross section, the bone cells, or **osteocytes** (os'tē ə sītz), were destroyed. But the cavity where they were living remains. You can see that the cells had many branches. Note the canals and rings of mineral. The canals were the routes for arteries, veins, and nerves, which nourished and controlled the osteocytes. The rings show that the bone mineral was laid down in layers. They are like tree rings, which are laid down as the tree grows larger in diameter.

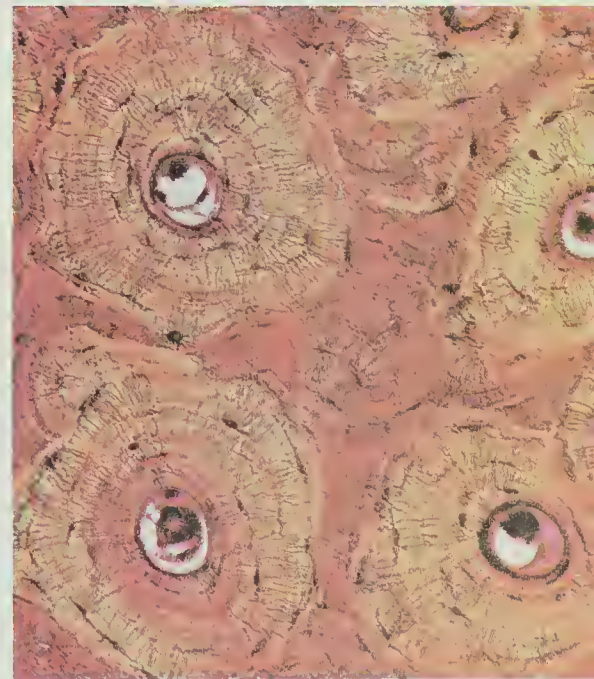
There are two basic kinds of bone tissue. One is called **compact bone** because it is very hard and dense. Compact bone forms the outside layer of most bones of the skeletal system. The other type of bone tissue is called **spongy bone**. Spongy bone has larger pores, is much lighter in weight, and has somewhat the same structure as a sponge. Spongy bone is found in the interior of most bones.

38-2 Cartilage tissue **Cartilage** (kär'tə lij) is a softer, more flexible tissue than bone. It forms most of the skeleton in the unborn child. From the time of birth to the

MAIN IDEA

Bone, the hardest and toughest tissue, is made up mostly of cell products. Compact bone forms the outer layer of most bones, while spongy bone makes up the interior.

A cross section of compact bone is shown below. The rings of mineral material were laid down by the bone cells, or osteocytes. The larger spaces contained blood vessels and nerves.



SCIENCE BACKGROUND

Technically, cartilage and bone are special types of connective tissue, but they are treated here as separate tissues.

Dense bone is made up of units called Haversian systems—a unit of concentric rings, or lamellae, with osteoblasts, longitudinal Haversian canals, lateral Volkmann's canals, and small canaliculi.

The technical name for spongy bone is *cancellous bone*, which means “lattice-work.” The growth of bone is a process that involves bone resorption by osteoclasts and bone formation by osteoblasts. The membrane surrounding the bone is the periosteum.



Long collagen fibers can be seen at the top center of the photograph above. Collagen is found in several types of connective tissue.

MAIN IDEA

The softer cartilage tissue is gradually replaced by bone tissue as a child grows to adulthood. Cartilage in the adult is found mainly in the nose, ears, joints, and intervertebral discs.

late teens most of the cartilage is in the process of being replaced by bone.

Cartilage tissue is mostly noncellular tissue, like bone. The noncellular part of the tissue consists of **collagen** (kol'ə jən) **fibers**, which are tough bands of protein and solid but flexible material that is blue-white in color. Cartilage is the gristle that you find at the end of a fried chicken drumstick.

In the adult skeleton, cartilage is found in the nose and ears. It is also found in many **joints**, the regions where bones come together. A strong type of cartilage, with many collagen fibers, is found in the **intervertebral** (in tər vēr'tə brəl) **discs**. These discs are the cushioning pads between the vertebrae. The cartilage in the ear has many

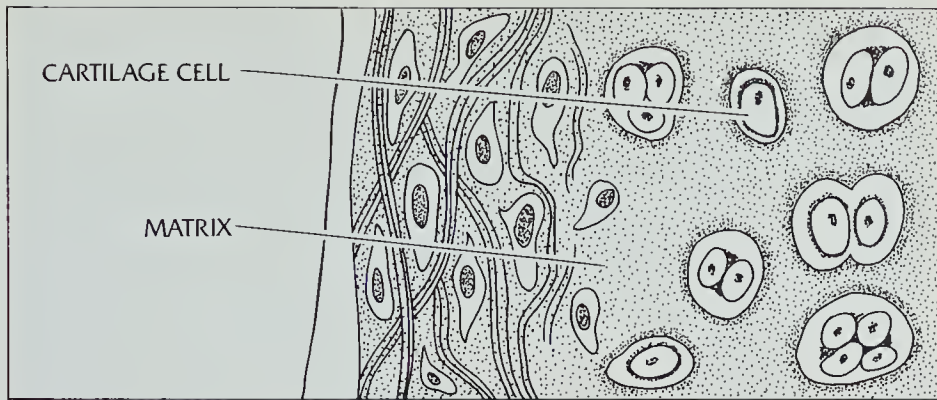
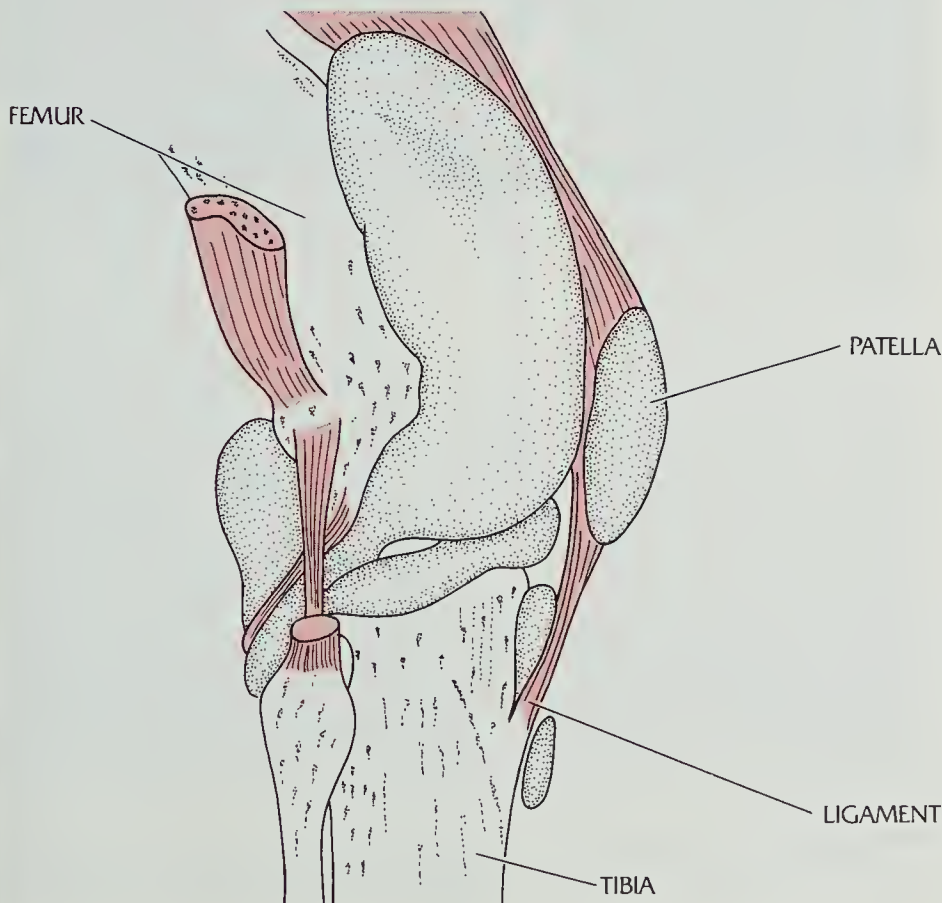


FIGURE 38-1 Cartilage tissue consists of cartilage cells interspersed throughout a flexible matrix.

elastic fibers that give the ear much more flexibility than the cartilage in the nose.

38-3 Connective tissue Connective tissue is found throughout the body. The main cells in connective tissue are **fibroblasts** (fī'brə blasts). Their chief product is collagen, which is formed into strong protein fibers. In the skeletal system the collagen fibers are arranged in dense,



SCIENCE BACKGROUND

The cells of cartilage are called chondrocytes. The noncellular material is made up largely of collagen. There are three types of cartilage. Hyaline cartilage makes up most of the fetal skeleton. It is the cartilage that is found at the ends of long bones and that connects the ribs to the sternum. Fibrous cartilage contains many collagen fibers and is the cartilage of the intervertebral discs. Elastic cartilage has a high percentage of elastic fibers and is found in the ear.

MAIN IDEA

Collagen fibers produced by fibroblasts form ligaments that hold the bones together.

SCIENCE BACKGROUND

The connective tissue of ligaments and tendons is technically called organized dense connective tissue. In unorganized dense connective tissue the fibers run in all directions such as in the skin and most muscle fascia.

FIGURE 38-2

Ligaments are composed mainly of collagen fibers. Ligaments join bones together.



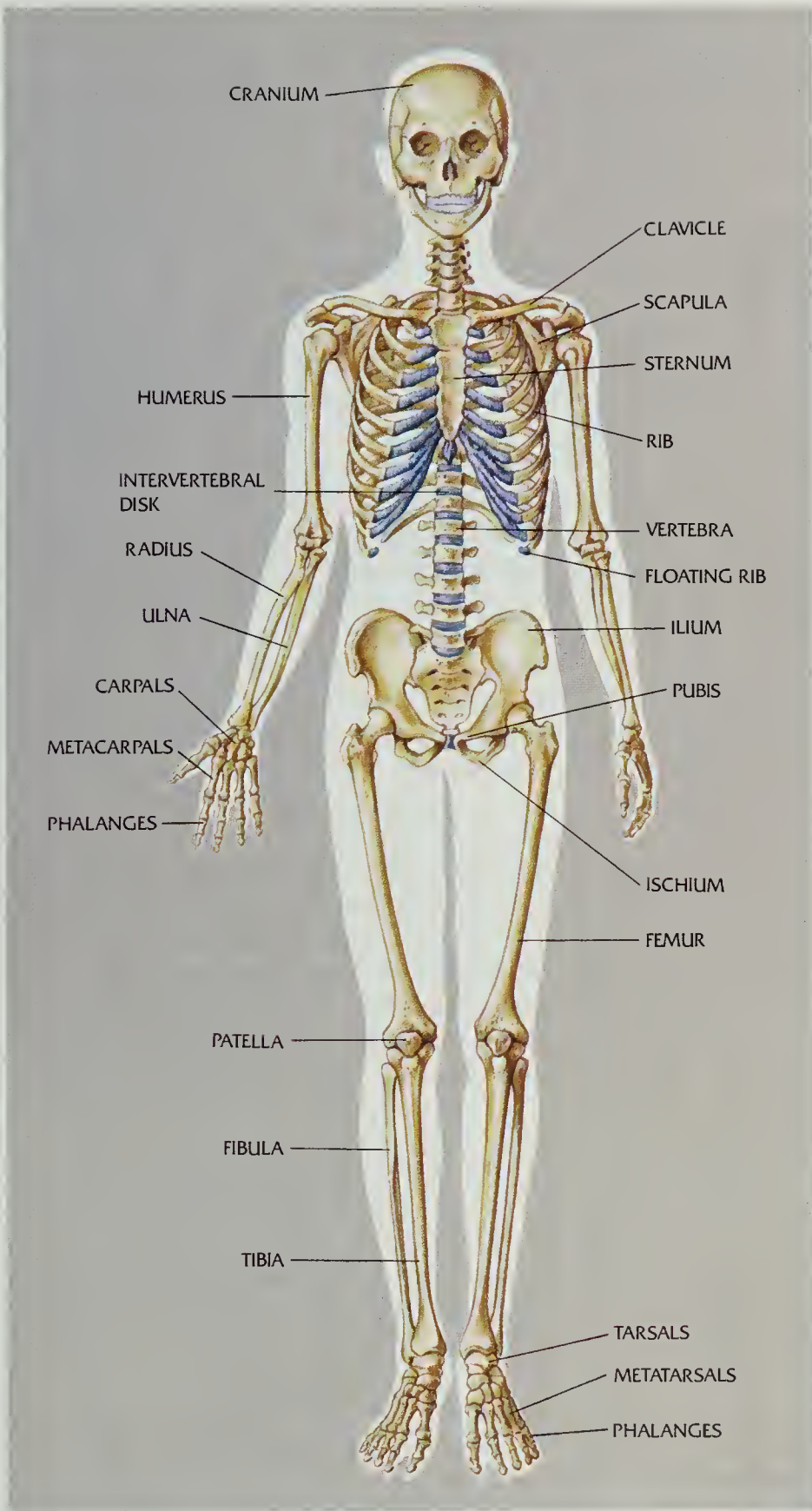
The skeletal system provides support for the body and protection for internal organs.

parallel bundles, in structures called **ligaments** (lig'mənts). The ligaments hold the bones together and are very strong. In football, ligaments are sometimes stretched or torn loose from their attachment to a bone. However, a ligament is rarely broken, except in very severe injuries.

MAIN IDEA

The skeletal system supports the body, protects the internal organs, assists in locomotion, and produces erythrocytes.

38-4 Functions of the skeletal system The skeletal system has many functions. One function is to provide support for the body. Without the skeleton our muscles and other organs would collapse. Another function of the skeleton is the protection of vital organs. The skull bones protect the brain. The vertebrae protect the spinal cord. The ribs protect the lungs and the heart. A third



SCIENCE TERMS

osteocytes
compact bone
spongy bone
cartilage
collagen fibers
joints
intervertebral discs
fibroblasts
ligaments
axial skeleton
appendicular skeleton
pectoral girdle
pelvic girdle
suture
mandible
fontanels
vertebral column
cervical vertebrae
thoracic vertebrae
lumbar vertebrae
sacrum
coccyx
sternum
clavicle
scapula
ilium
ischium
pubis
fibrous joint
cartilagenous joint
synovial joint
fracture
simple fracture
compound fracture
greenstick fracture

FIGURE 38-3 Some of the important bones of the human skeletal system are identified in this illustration.

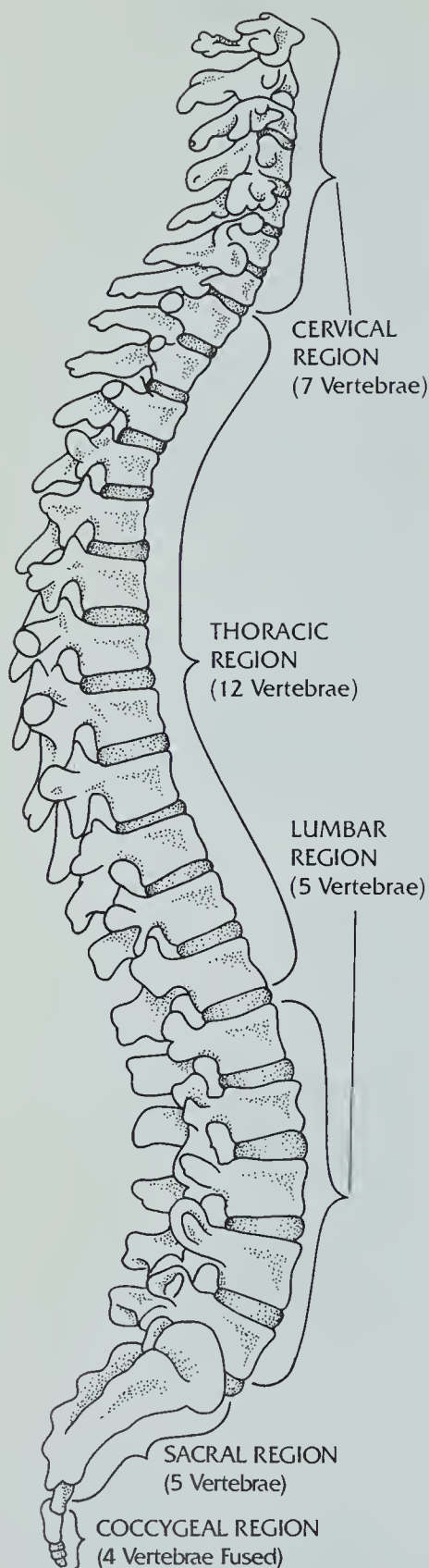


FIGURE 38-4

The vertebral column is made up of 24 interconnected vertebrae. The vertebral column protects the spinal cord.

function of the skeleton is to assist in locomotion, the movement of the body and its parts. In the function of locomotion the skeleton works as a team with the muscular system. In the spongy bone, blood cells are manufactured in the red marrow, which fills most of the pores.

38-5 Structure of the skeletal system The skeletal system is usually divided into two parts. One part, the **axial** (ak'sē əl) **skeleton**, forms the vertical axis of the body and consists of the skull, vertebrae, and bones of the thorax. The other part, the **appendicular** (ap ən dik'yə lər) **skeleton**, includes the appendages (arms and legs) and their girdles. The girdles are the bones that the appendages attach to. The arms attach to the **pectoral** (pek'tər əl) **girdle**, which includes the bones of the shoulder. The legs attach to the **pelvic** (pel'vik) **girdle**, which includes the bones of the hip.

38-6 Bones of the axial skeleton The skull consists of 28 bones. All but one of the skull bones are linked together into immovable joints. The junction between such bones is called a **suture** (sü'chər). Usually the suture is irregular in shape. The one movable bone of the skull is the lower jaw, or **mandible** (man'də bəl), which is used in chewing food. In the skull of a newborn baby there are six **fontanels** (fon tə nels'), usually called soft spots, where bone has not yet formed. These spaces allow the skull to become deformed during the birth process, and they are normally filled in at the end of two years.

The backbone, or **vertebral** (vēr'tə brəl) **column**, is made up of 24 separate vertebrae. The vertebral column is the only support for the upper part of the body. It must be flexible, yet strong enough to protect the delicate spinal cord that travels most of its length.

There are four separate regions in the vertebral column. The **cervical** (sēr'və kəl) **vertebrae** (7) form the neck region. The **thoracic** (thô ras'ik) **vertebrae** (12) attach to the ribs and form the thorax. The **lumbar** (lum'bər) **vertebrae** (5) are in between the thorax and the pelvic girdle and make up what is called the "small of the back." The fourth region of the vertebral column is made up of two bones that are fused vertebrae. These two bones, the **sacrum** (sā'krəm) and the **coccyx** (kok'siks), form the bottom of the vertebral column and join it to the pelvic girdle.

There are 12 pairs of ribs that form most of the thorax. The upper 7 pairs attach to the thoracic vertebrae at the back and to the breastbone, or **sternum** (stēr'nəm), in

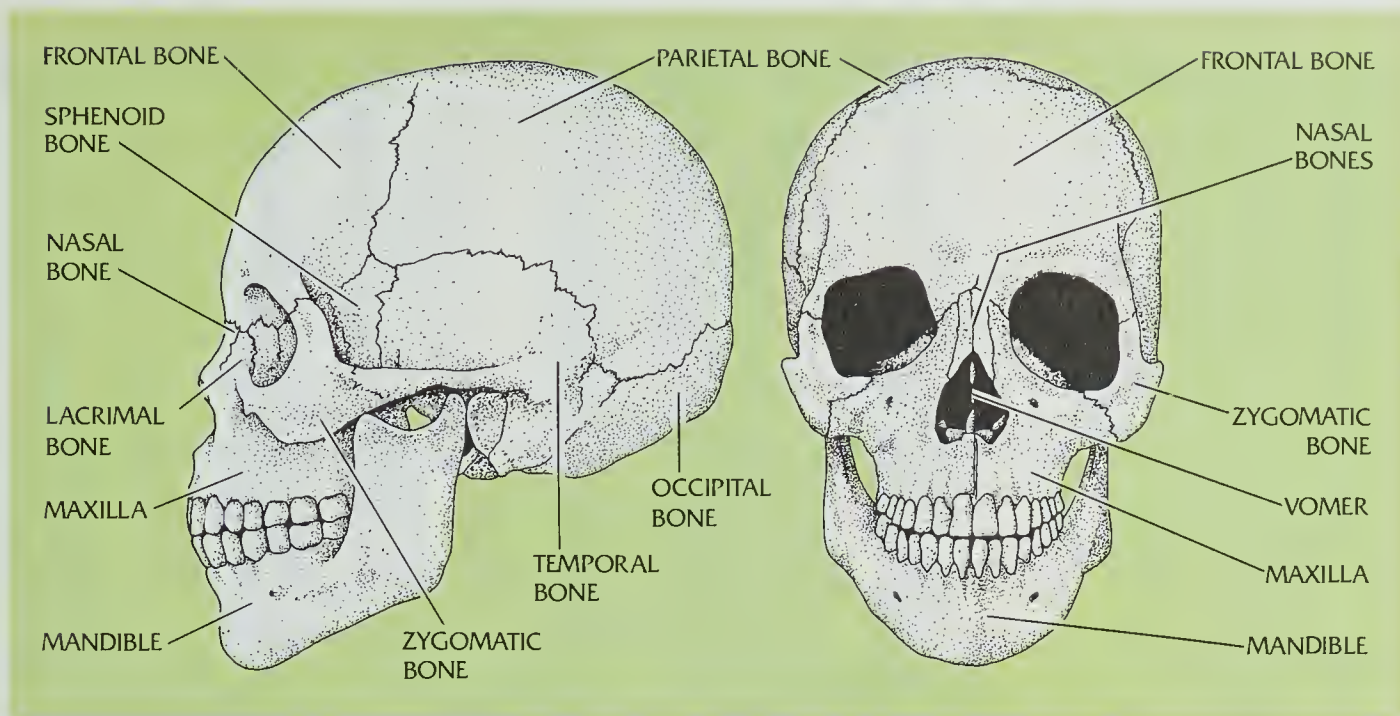


FIGURE 38-5

Some of the bones of the human skull and face are identified in this figure.

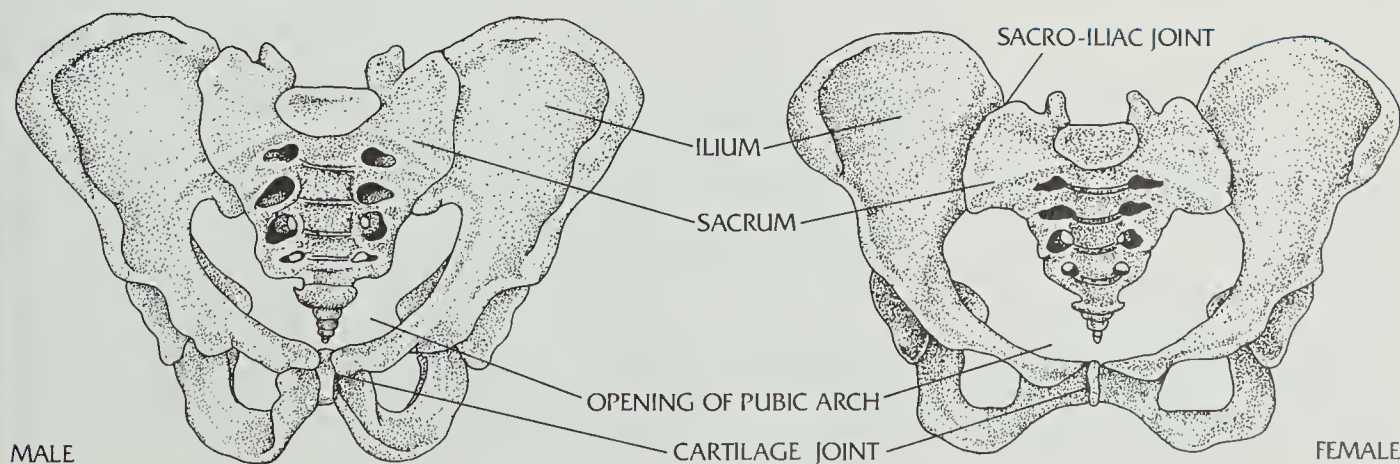
the front. The next 3 pairs attach to the thoracic vertebrae, but not directly to the sternum. Instead, they attach to other ribs. The bottom 2 pairs of ribs are unattached at the front and are called floating ribs.

38-7 Bones of the appendicular skeleton The main bones of the arms and legs are called the long bones of the skeleton. The long bones are mostly responsible for body action and movement. The hands and feet are at the ends of the long bones. They are made up of numerous small bones that allow for great flexibility.

MAIN IDEA

The long bones are primarily responsible for body movement. The pectoral girdle is composed of two bones, arranged to allow free movement of the shoulder. The pelvic girdle provides a place for powerful leg muscles to attach.

FIGURE 38-6 The pelvic girdles in a human male and a human female are compared in the illustration below.



The pectoral girdle is composed of the collar bone, or **clavicle** (klav'ə kəl), and the shoulder blade, or **scapula** (skap'yə lə). The arrangement of the two pectoral bones allows free movement of the shoulder, even when the arms are held at the sides of the body.

The pelvic girdle is a solid structure, made up of three different bones that are fused together: the **ilium** (il'ē əm), **ischium** (is'kē əm), and **pubis** (pyü'bis). The pelvic girdle provides a large, solid region where the powerful muscles that move the upper legs can attach. Its shape allows room for the abdominal organs. In the female it is broader and has a larger central opening to allow for childbearing and birth.



FIGURE 38-7

The elbow is an example of a hinge joint. The shoulder is an example of a ball-and-socket joint.

MAIN IDEA

Fractures, or broken bones, are slow to heal because bones are not well supplied with blood, and the process of bone making is very slow.

38-8 Joints There are three basic kinds of joints. One, called the **fibrous** (fī'brəs) **joint**, is the type found in the skull. In the fibrous joint the bones are united by strong fibrous connective tissue, and most fibrous joints are immovable.

A second type of joint is the **cartilagenous** (kār tə laj'ə nəs) **joint**, which is made up of cartilage. All the joints between the ribs and the sternum are cartilagenous joints. Cartilage also forms the joint between the lower ends of the pelvic bones.

The third type of joint is the **synovial** (si nō'vē əl) **joint**. The synovial joint has a joint cavity and a fluid called synovial fluid that serves as a lubricant. The synovial joints are movable. Some glide like the hand bones or hinge like the elbow and knee. Other joints pivot like the skull and first vertebrae or rotate like the ball-and-socket joints of the upper arm and leg.

38-9 Fractures A bone break is called a **fracture** (frak'chər). If the bone is broken but its edges have not broken through the skin, it is called a **simple fracture**. If the broken bone has pierced the skin, it is called a **compound fracture**. A fracture common in young people occurs when their more flexible bones bend and break, causing a **greenstick fracture**.

Fractures heal much more slowly than injuries to other tissues, such as the skin or muscles. There are two reasons for this slowness. First, the process of bone making—the laying down of mineral deposits by bone cells—is a slow process, when compared to other body processes. In addition, the blood supply to the bones is limited. This means that the bone cells do not get the good service received by most other cells of the body.

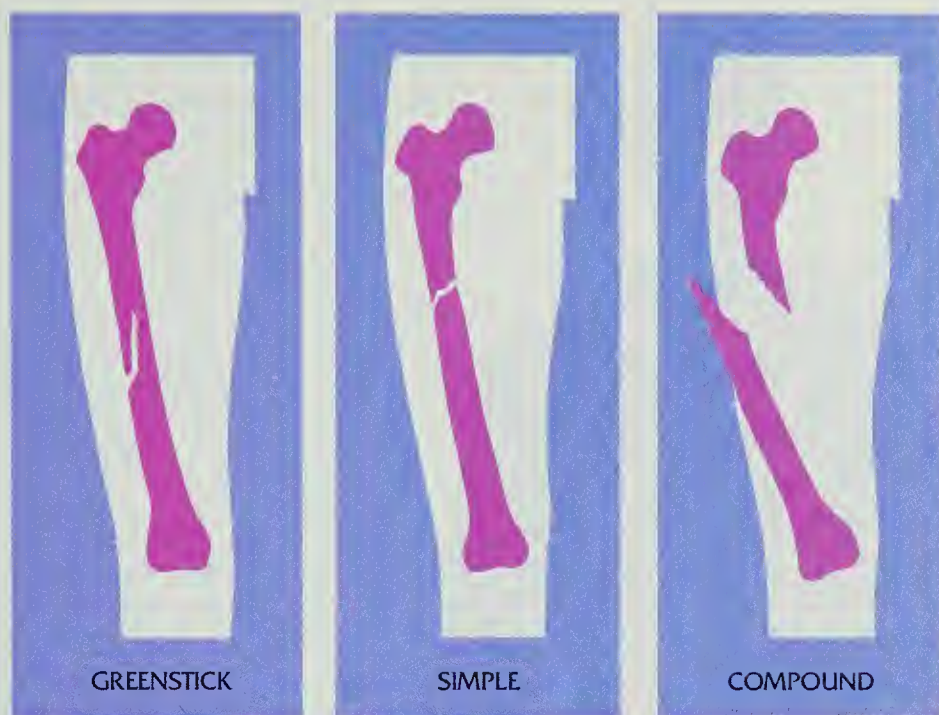


FIGURE 38-8 The three types of fractures—simple, compound, and greenstick—are illustrated in the figure above.

CHECK YOUR FACTS

1. What three basic kinds of tissue make up the skeletal system?
2. Compare the structure and location of compact bone and spongy bone.
3. What makes cartilage tissue tough? When is the most cartilage present?
4. What are intervertebral discs?
5. What are fibroblasts? What do they produce?
6. What are ligaments?

The Muscular System

38-10 Skeletal muscles A true description of the muscular system should include all three types of muscles in the human body. One type is smooth muscle, which is found in the internal organs and is involuntary, or not under our conscious control. The second type is cardiac muscle, found only in the heart.

Usually the term *muscular system* is meant to describe just one type of muscle. This is the muscle called **skeletal muscle**, which is mostly attached to the skeleton and is under our conscious, or voluntary, control.

ANSWERS TO CHECK YOUR FACTS

1. Bone, cartilage, and connective tissue.
2. Compact bone is very hard and dense—it forms the outer layer of most bones. Spongy bone is porous and more lightweight—it forms the inside of most bones.
3. Collagen fibers. In the unborn child.
4. Cushioning pads of cartilage found between the vertebrae.
5. The main cells in connective tissue. Collagen.
6. Collagen structures that hold bones together.

SCIENCE BACKGROUND

Try to borrow X rays of broken bones to illustrate the types of breaks and the healing process. Another type of fracture is the comminuted fracture, where there are fragments of bone in the tissue surrounding the break.

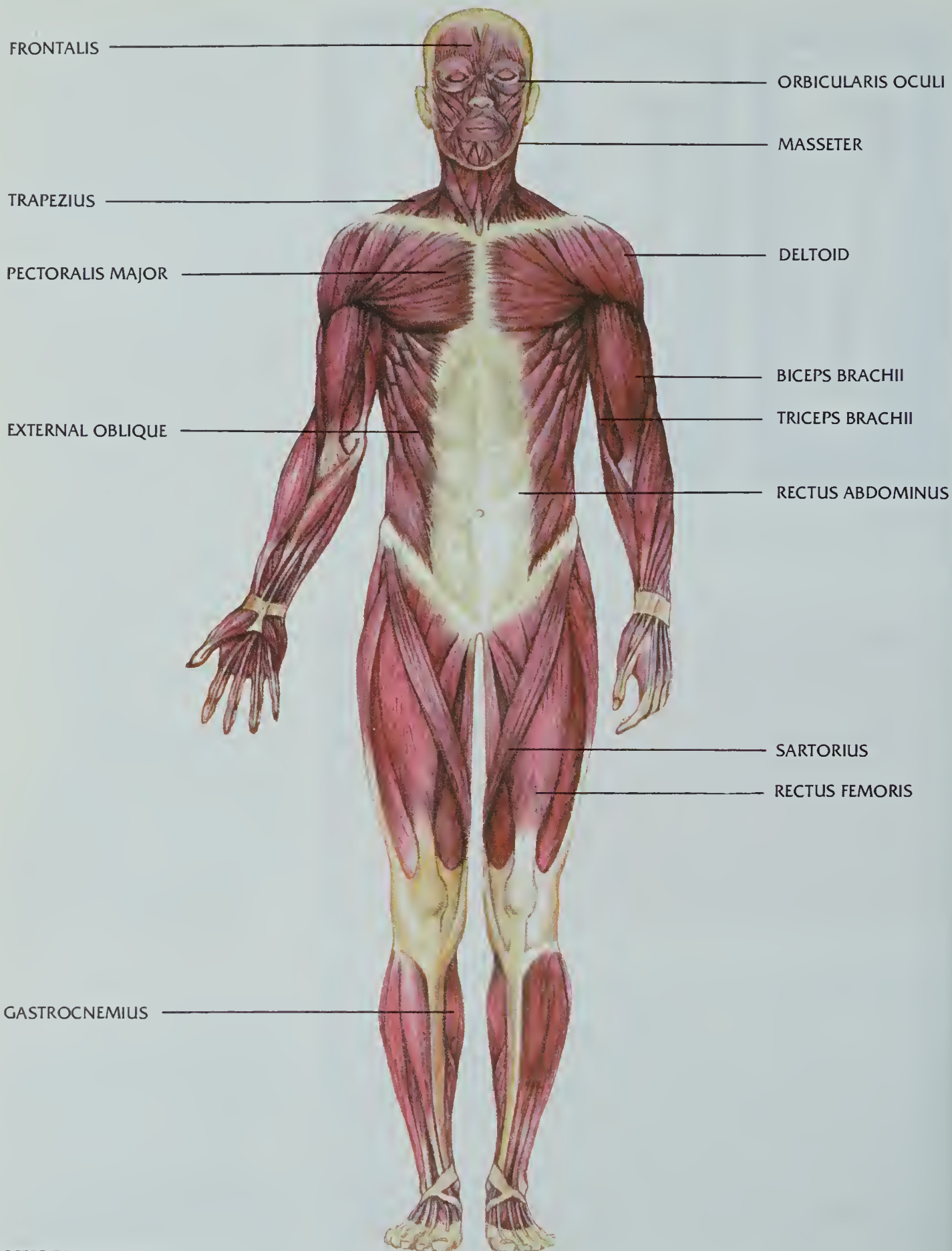
The replacement bone is called callus, and the external callus forms a hump on the healing bone that sometimes remains as the only sign of the fracture.

MAIN IDEA

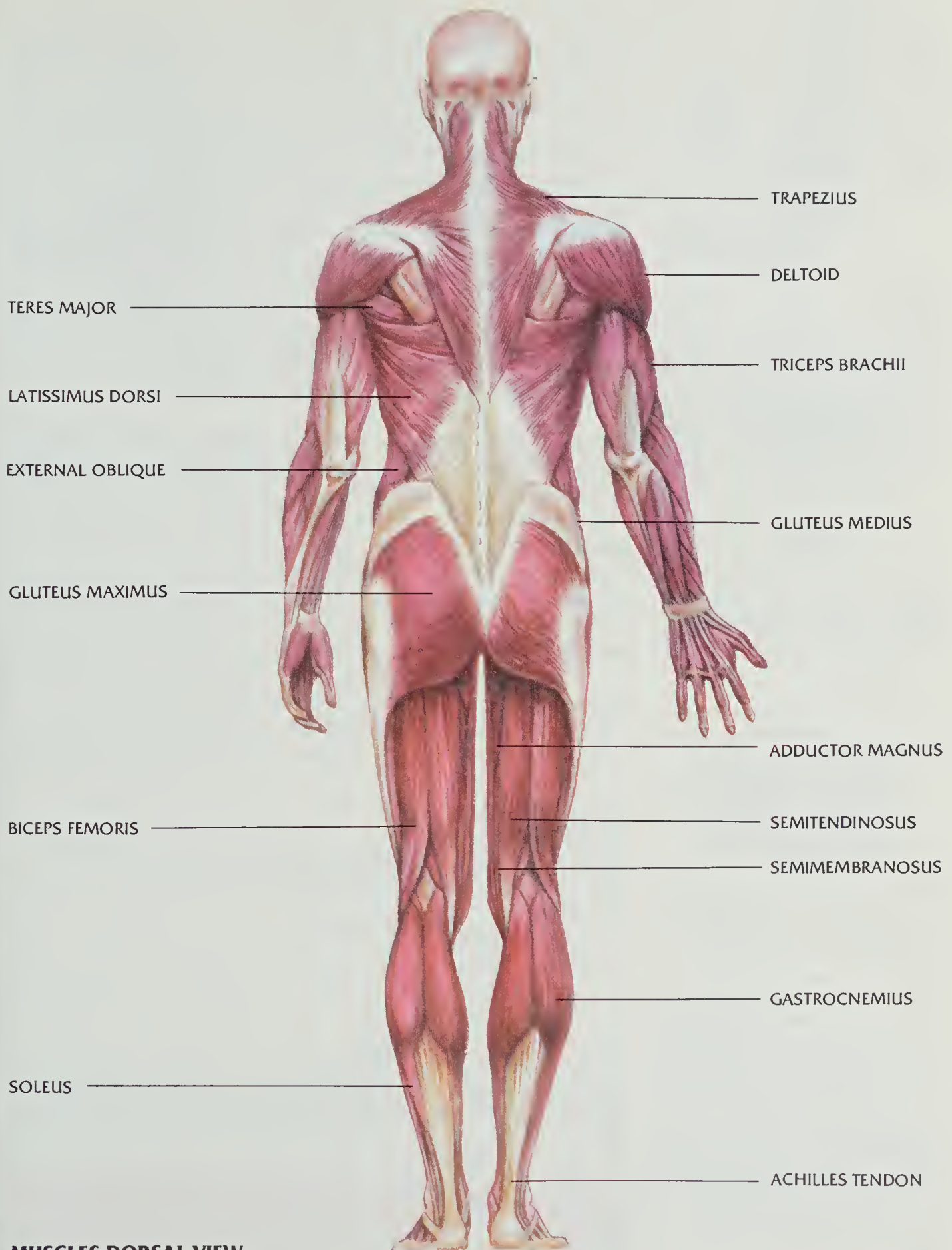
The muscles attached to the skeleton are primarily voluntary muscles and are called skeletal muscles.

SCIENCE BACKGROUND

There are about 700 different skeletal muscles.



MUSCLES VENTRAL VIEW



MUSCLES DORSAL VIEW

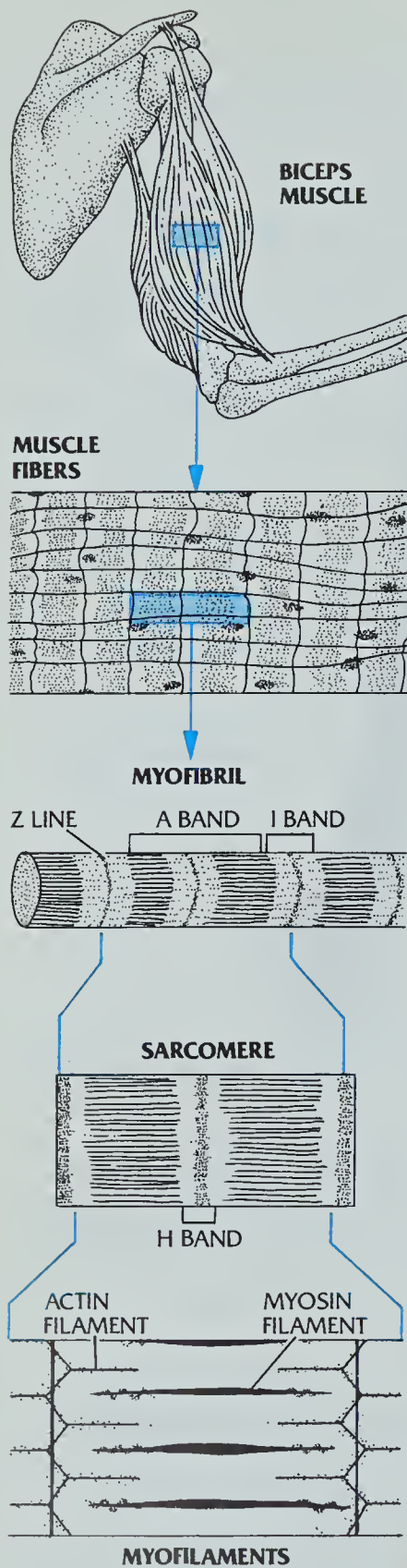


FIGURE 38-10

The structure of skeletal muscle is shown in increasing detail in this figure. The fine structure was determined with the use of the electron microscope.

38-11 Skeletal muscle tissue Skeletal muscle tissue has an unusual structure. It is made up of long bundles of fibers, which are a unique type of multinucleate (many nuclei) cell. Under the light microscope, stripes, or striations, can be seen running across the fibers. For this reason, skeletal muscle is also called striated muscle.

Only after studies with the electron microscope was the true structure of skeletal muscle tissue discovered. The electron microscope showed that each fiber is made up of bundles of smaller threadlike bodies called **myofibrils** (mī ə fī'brəls). Moreover, further studies of the myofibrils showed that they, in turn, were made up of two different-sized filaments. The thinner filaments are composed of the protein **actin** (ak'tin). The thicker filaments are composed of another protein, called **myosin** (mī'ə sin).

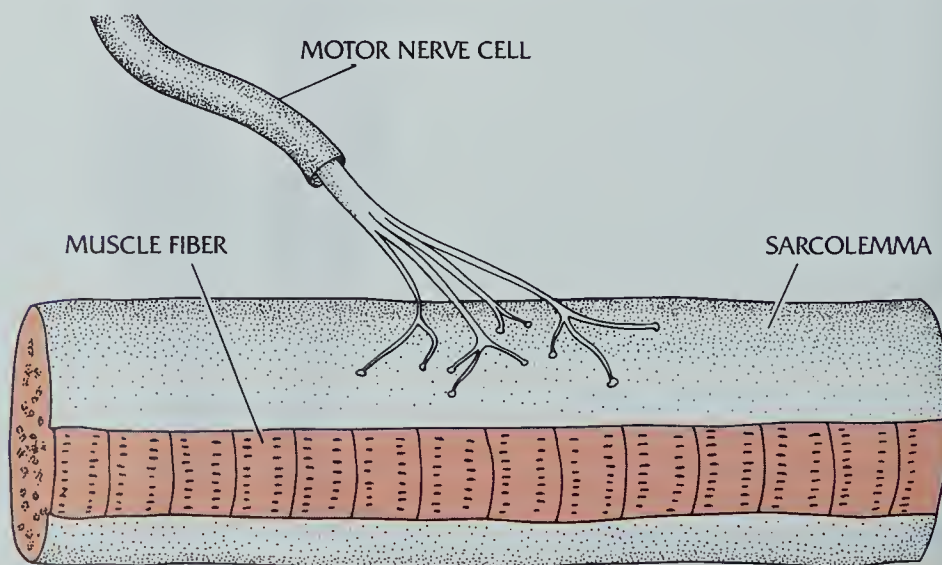
38-12 The motor nerve impulse and muscle contraction

Skeletal muscles contract as the result of direct nerve impulses from motor nerves. The ends of a motor nerve are arranged over the membrane, or **sarcolemma** (sär kō lem'ə), of the muscle fiber. When a nerve impulse reaches the ends of the motor nerve, the transmitter acetylcholine is released. Like a neuron, the outside of the sarcolemma is more positively charged than the inside. The acetylcholine causes the sarcolemma to depolarize. This depolarization triggers a chain of events that causes the muscle fiber to contract, or get shorter.

Inside the fiber, along with the myofibrils, are scattered nuclei, mitochondria, and a network of sacs and tubules.

FIGURE 38-9

The release of a chemical transmitter from the axon of a motor nerve cell results in the contraction of the muscle fiber.



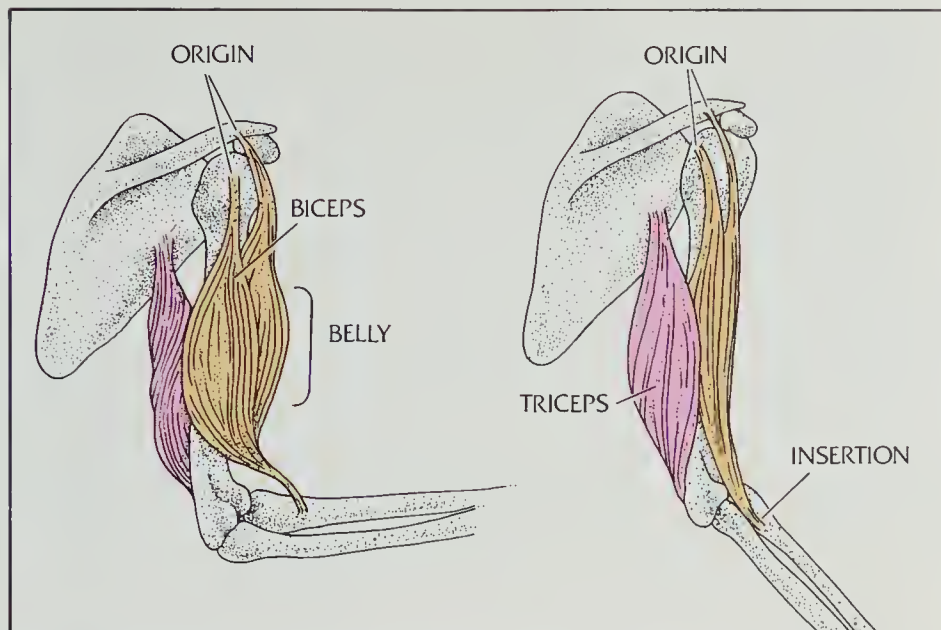


FIGURE 38-11 The actions of the biceps muscle and the triceps muscle in flexing and extending the lower arm are shown in this figure.

Part of the network is like the endoplasmic reticulum of other cells, but it is called the **sarcoplasmic** (sär kō plaz'mik) **reticulum**. Other tubules, called **T tubules**, connect with the sarcoplasmic reticulum and with the sarcolemma, the outside membrane.

A simplified explanation of the events that cause muscle contraction is as follows: The depolarization stimulates the T tubules, which, in turn, stimulate the sarcoplasmic reticulum to release calcium ions (Ca^{++}) near the myofibrils. The calcium ions actually start the contraction process. They stimulate the thin fibers, or actin, to slide toward each other and toward the thick fibers, or myosin. The depolarization stimulates the breakdown of ATP, which provides the energy for the contraction. After the contraction the calcium ions recombine with the sarcoplasmic reticulum, and the actin fibers return to their normal position. When this happens the muscle fiber relaxes.

38-13 The work of muscles Skeletal muscles are attached to bones by tough bands of connective tissue called **tendons** (ten'dəns). Like ligaments, which attach bones to bones, the tendons are very strong. In injuries they may be pulled away from bones, or the bone may be broken. Rarely is a tendon pulled apart in an injury.

Muscles usually do their work by contracting, or pulling on tendons, which, in turn, pull on bones. Also, muscles that move a bone are usually attached to some other bone.

SCIENCE TERMS

skeletal muscle
myofibrils
actin
myosin
sarcolemma
sarcoplasmic reticulum
T tubules
tendons
origin
insertion
belly

SCIENCE BACKGROUND

The interior of a muscle fiber contains sarcoplasm, which is similar to cytoplasm but more liquid in form. The actin and myosin filaments in the myofibrils do not run the whole length of the myofibril. They are self-contained in subunits called sarcomeres which are partitioned by regions called Z bands.

Myosin also is an enzyme that catalyzes the breakdown of ATP into ADP and the release of energy to power the contraction. A supplemental energy molecule, creatine phosphate (CP), also is involved. Enzymes and CP restore ATP, but in times of reduced activity, the creatine is rephosphorylated by ATP.

MAIN IDEA

Muscles usually work by contracting, or pulling on tendons, which, in turn, pull on bones. Muscles usually work in pairs with the contraction of one and the relaxation of the other.

ANSWERS TO CHECK YOUR FACTS

1. Cardiac muscle—heart. Smooth muscle—internal organs. Skeletal muscle—those muscles that are attached to the skeleton and are under conscious control.
2. Threadlike bodies that make up the skeletal muscle fibers. Actin and myosin.
3. The membrane of the muscle fiber. It changes polarity.
4. The sarcolemma and the sarcoplasmic reticulum.
5. Ca^{++} is released and muscle contraction occurs.
6. Ca^{++} recombines with the sarcoplasmic reticulum, and the actin fibers return to their normal position.

ANSWERS TO REVIEW QUESTIONS

1. Osteocytes, and minerals formed from the calcium and phosphorous deposits of osteocytes.
2. In the nose, the ears, the intervertebral discs, and in many joints.
3. Ligaments link bones to other bones, and tendons attach muscles to bones. Yes.
4. It consists of 28 bones. All but the mandible are linked together into immovable joints connected by fibrous tissue. Sutures between the bones are irregular in shape. A baby's skull has six fontanels, or spots where bone development has yet to occur.
5. Cervical vertebrae (7) of the neck region; thoracic vertebrae (12), which attach to the ribs and form the thorax; lumbar vertebrae (5) between the tho-

A good example to illustrate these facts is the biceps muscle of the upper arm. This muscle lies over the bone of the upper arm. But its function is to raise the lower arm. It does its work through tendons that are anchored on the lower arm bones. When the biceps muscle contracts, the tendons raise the lower arm.

Another fact about muscles is that they normally work in pairs and in a coordinated manner. We mentioned the biceps muscle that raises the lower arm. On the opposite side of the upper arm is the triceps muscle that must relax before the biceps muscle can do its work. The opposite must occur when the lower arm is straightened. The triceps muscle must contract and the biceps muscle must relax. The cerebellum coordinates the motor impulses to the different muscle fibers, so that the muscles react smoothly.

38-14 Muscle terms Several terms are used to describe muscle locations and functions. The **origin** of a muscle is the end of the muscle that is attached closer to the central axis of the body. Also it is the part of the muscle that moves the least when the muscle contracts. The origin of the biceps muscle is on the scapula.

The **insertion** (in sēr shən) of a muscle is the opposite end from the origin and the farthest from the central axis. It is the part that moves the most. The insertion of the biceps muscle is on the lower arm's bones—the radius and the ulna.

The actual muscle, between the tendons of origin and of insertion, is called the **belly** of the muscle. But some muscles have the belly split into two or more parts. The biceps muscle has two parts; the triceps muscle has three. A large muscle on the upper leg, called the quadriceps femoris, is made up of four parts. Most muscles have been given names that describe their position, action, origin, and insertion.

CHECK YOUR FACTS

1. What three types of muscles are there? For each type, name one structure that has that type.
2. What are myofibrils? Of what proteins are they made?
3. What is the sarcolemma? What happens when it contacts acetylcholine?
4. What two structures do the T tubules connect?
5. What happens when the sarcoplasmic reticulum is stimulated?
6. What happens after contraction?

SUMMARY

The three tissues of the skeletal system—bone, cartilage, and connective tissue—are all made up mostly of cell products. Minerals in bone and collagen in the others make these tissues very strong. Most bones have compact bone on the outside and spongy bone in the middle. Cartilage is more flexible than bone and is found in joints and in the intervertebral discs. Connective tissue forms ligaments and tendons. It is found throughout the body. The skeletal system supports the body, protects the internal organs, assists in locomotion, and manufactures erythrocytes. Skeletal muscle is used for locomotion. It moves the bones of the skeleton. Muscles normally work in pairs and in a coordinated manner.

REVIEW QUESTIONS

1. What is bone tissue made of?
2. Where is cartilage found in the adult human?
3. Explain the difference between ligaments and tendons. Are they both connective tissue?
4. Describe the structure of the skull. How is the skull of a baby different from that of an adult?
5. List the name and number of vertebrae in each region of the vertebral column.
6. What bones make up the pelvic girdle? The pectoral girdle? To which skeleton do they belong?
7. What are movable joints called? Describe some types of movement seen in these joints.
8. Distinguish between a simple and a compound fracture. Why do bones heal more slowly than other tissues?
9. Can you explain what causes the bands seen in skeletal muscle tissue?
10. Describe how a nerve impulse causes a muscle to contract.

ANALYSIS AND APPLICATION

1. When a biceps relaxes after being contracted, what is happening to the following: (a) the actin of the biceps; (b) the position of your hand; (c) the calcium in the sarcoplasmic reticulum of the biceps?
2. What advantage is it for the unborn baby to have cartilage instead of a completely bony skull?
3. What are the two most abundant cell products found in the skeletal system? Which one is also found in the muscular system?

thorax and the pelvic girdle, and the sacrum and the coccyx (2 fused vertebrae), which form the bottom of the vertebral column and join it to the pelvic girdle.

6. Ilium, ischium, and pubis
Clavicle and scapula
Appendicular skeleton

7. Synovial joints. They can glide, hinge, pivot, or rotate.

8. A compound fracture is a simple fracture that also breaks the skin. Bones receive less blood than other tissues, and the fracture must be mended with mineral deposits. This process takes more time than the cell development that mends other tissues.

9. The myofibrils that make up the fibers are, in turn, made up of alternating groups, or bands, of thin and thick protein filaments.

10. When the impulse reaches the end of the axon, acetylcholine is released. This causes the sarcolemma to depolarize. The depolarization stimulates the T tubules, which, in turn, stimulate the sarcoplasmic reticulum to release calcium ions. The calcium ions cause the actin of the myofibrils to slide toward each other and toward the myosin. It is this action that contracts the muscle.

ANSWERS TO

ANALYSIS AND APPLICATION

1. The actin fibers return to their normal position. The hand doesn't move. The calcium recombines with the sarcoplasmic reticulum.
2. The flexible cartilage allows the head to be deformed during the birth process without permanent damage.
3. Calcium and phosphorus.
Calcium

39 *The Reproductive*



OBJECTIVES

- To understand that the main function of the male reproductive system is to produce sperm and hormones that relate to reproduction
- To appreciate that hormones from the pituitary stimulate and control secondary sex characteristics and the function of the testes
- To understand that the hormones from both the pituitary and the ovary regulate the menstrual cycle
- To describe the events of the menstrual cycle
- To discuss the basic processes of fertilization, of early development, and of the implantation of the human embryo
- To appreciate the role of the placenta in maintaining pregnancy
- To understand the basic stages of fetal development
- To explain how the birth process occurs
- To appreciate the function of lactation and how it is controlled

System

Male and Female Systems

39-1 The male reproductive system The male reproductive system has two main functions. One is to produce the male gametes, which are called **spermatozoa** (spër mə tə zō'ə), or sperm. The second function is to produce the hormones necessary to make the reproductive system work and to give the male his distinctive physical characteristics. The *testes* (sing. *testis*) are the organs that produce the sperm. In addition, the testes also produce the male hormones.

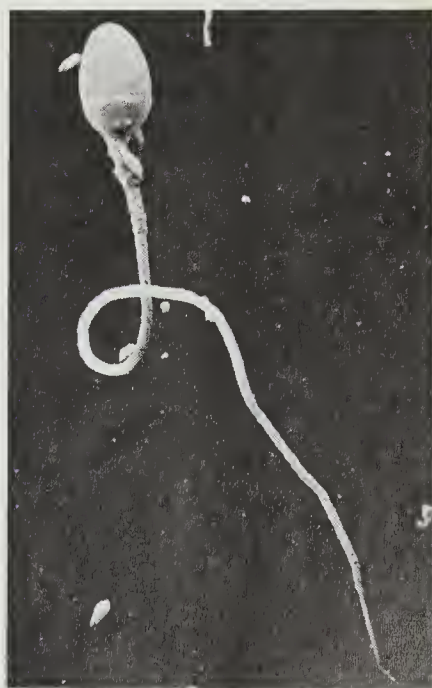
The sperm are produced in small tubules inside the testes. From these tubules the sperm collect in the **epididymis** (ep'ə did'ə mis), which is a coiled tube about 6 meters long. From there they are stored in a tube, the **vas deferens** (vas def'ə renz). Connected to the vas deferens are two glands, the **seminal vesicle** (sem'ə nəl) and the **prostate** (pros'tāt). They contribute a liquid called **semen** (sē'mən) to the sperm. Semen provides food and the proper environment for survival of the sperm. About 400 million sperm are released through the **penis** (pē'nis) into the **vagina** (və jī'nə) of the female reproductive system. The sperm swim upward and can survive for one or two days.

39-2 Hormones of the male reproductive system The male reproductive system begins to mature at the approximate age of 13, at a time called **puberty** (pyü'bər tē). Puberty is started by hormones from the anterior lobe of the pituitary gland. One hormone,

MAIN IDEA

The male reproductive system produces sperm and hormones. Sperm are produced in the testes, mixed with semen, and passed through the penis into the vagina of the female.

Sperm cells are the reproductive cells of the male. They are produced in the testes.



from TISSUES AND ORGANS, A TEXT-ATLAS OF SCANNING ELECTRON MICROSCOPY by Richard G. Kessel and Randy H. Kardon, W.H. Freeman and Company. Copyright © 1979

FIGURE 39–1

The structures of the male reproductive system are shown in the illustration at right. The testes produce sex hormones as well as sperm.

SCIENCE BACKGROUND

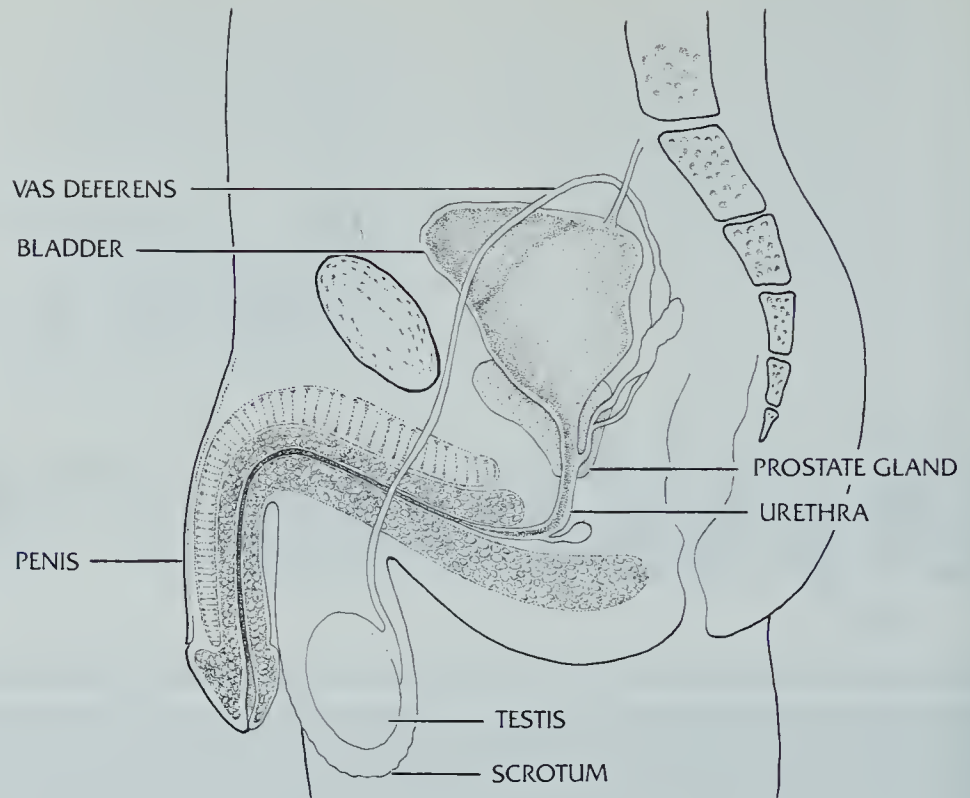
The tubules in the testes—the seminiferous tubules—would, if stretched end to end, extend 240 m. The term *seminal vesicle* was given to the glands when it was thought that they were a reservoir for sperm storage. Sperm are stored in the vas deferens.

SCIENCE BACKGROUND

The hormones produced by the testes are called androgens, but since testosterone has by far the dominant role, we have only included it in the discussion.

SCIENCE TERMS

spermatozoa
epididymis
vas deferens
seminal vesicle
prostate
semen
penis
vagina
puberty
follicle-stimulating hormone (FSH)
interstitial cell-stimulating hormone (ICSH)
interstitial cells
testosterone
secondary sex characteristics
ova
follicles
estrogen
luteinizing hormone (LH)
progesterone



follicle-stimulating hormone, or **FSH**, stimulates the development of the tubules in the testes and the manufacture of sperm. Another hormone from the anterior pituitary, **interstitial cell-stimulating hormone**, or **ICSH**, stimulates the nontubule cells of the testes, called **interstitial** (in tər stish'əl) **cells**. The interstitial cells produce male hormones, the most important being **testosterone** (tes tos'tə rōn).

Testosterone is mostly responsible for the development of the male **secondary sex characteristics**. The secondary sex characteristics include the lowering of the voice and the growth of a beard and body hair in the pubic region and under the arms. These changes occur gradually after the beginning of puberty and are usually fully developed by the age of 18.

39–3 The female reproductive system The female reproductive system has the same two functions as the male reproductive system. One is to produce the gametes, or **ova** (ō'və) (sing. *ovum*), with which the sperm unite in reproduction. The second function is to produce the hormones that make the system work and that cause the female to develop her distinctive secondary sex characteristics. However, the demands upon the female reproductive system are more complex. The system must produce ova, carry and nourish the developing human,

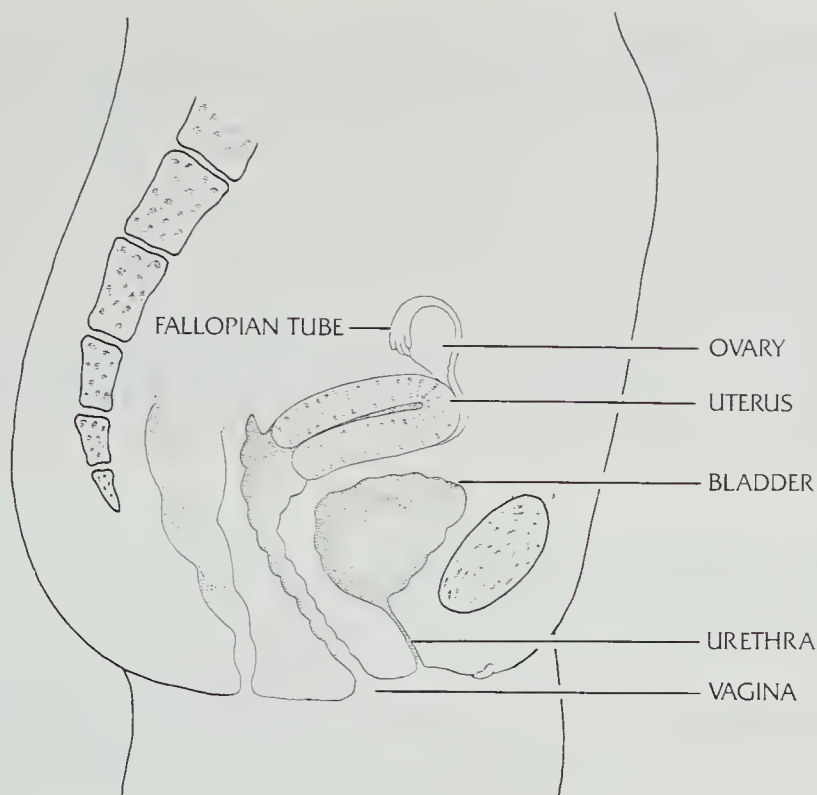


FIGURE 39-2

The structures of the female reproductive system are shown in the illustration at left. The ovaries produce eggs and sex hormones.

SCIENCE BACKGROUND

At the time of birth or shortly after, the ovaries have an estimated 100 000 to 400 000 potential follicles. Only 300 to 400 ever develop over the reproductive lifetime of the female. Technically the follicle is called the Graafian follicle.

and be prepared to feed a newborn baby for several months.

The main organs of the female reproductive system are the two ovaries, which are almond-shaped and about 3 cm long. The interior of each ovary is mostly made up of connective tissue. The outside layer consists of cells that can develop into special structures known as **follicles** (fol'ə kəlz). The ova develop in the follicles.

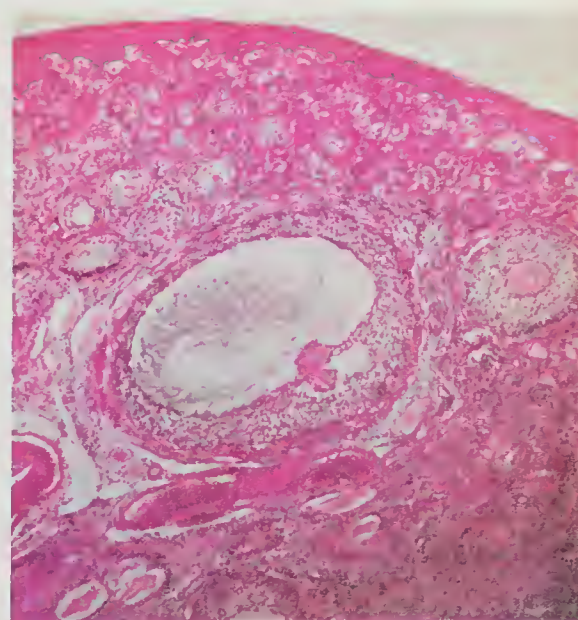
39-4 Hormones that stimulate follicle development The same two anterior pituitary hormones that stimulate the male reproductive system also stimulate the female system. Follicle-stimulating hormone, or FSH, stimulates the growth of the ovaries and the development of the follicles, where the ova are produced. FSH also stimulates the ovaries to produce a hormone called **estrogen** (es'trə jən), which has a number of effects upon the female body.

The hormone called interstitial cell-stimulating hormone (ICSH) in the male is called **luteinizing** (lū'tē ən ī zēng) **hormone**, or **LH**, in the female. LH also stimulates the development of the follicles and the production of estrogen by the ovaries. In addition, LH stimulates the ovaries to produce a second hormone called **progesterone** (prō jes' tə rōn). Estrogen and progesterone have very important roles in the reproductive process.

MAIN IDEA (39-4)

FSH and LH from the pituitary stimulate the development of follicles and the production of hormones by the ovaries.

A section of an ovary is shown below. FSH and LH from the pituitary stimulate follicle development and the production of sex hormones.



ANSWERS TO CHECK YOUR FACTS

1. To produce sperm; and to produce hormones that make the reproductive system work and give the male his secondary sex characteristics.
2. The testes.
3. The former collects sperm produced in the tubules. The latter stores the sperm.
4. In the seminal vesicles and the prostate. Semen provides the sperm with food and a proper environment.
5. FSH causes the development of tubules in the testes and the production of sperm. ICSH induces interstitial cells to produce testosterone. Testosterone stimulates the development of secondary sex characteristics.

MAIN IDEA (39–5)

The ovum is released from the ovary into the Fallopian tube, and fertilization may occur near the middle of a 28-day cycle called the menstrual cycle.

SCIENCE BACKGROUND

The released egg is said to be “swept” from the surface of the ovary by the undulating open end of the Fallopian tube.

MAIN IDEA

Hormones control the menstrual cycle. They stimulate development of the ovum and preparation of the uterus. If fertilization does not occur, the uterus lining breaks down and is discharged during the menstrual period.

CHECK YOUR FACTS

1. What are the two functions of the male reproductive system?
2. What organ achieves the functions that are listed in the question above?
3. What are the functions of the epididymis and the vas deferens?
4. Where is semen produced? What purpose does it serve?
5. What are the effects of FSH and ICSH? What does testosterone do?

The Menstrual Cycle, Pregnancy, and Birth

39–5 The menstrual cycle Ova are released from the ovaries and reproduction can occur during a 28-day cycle called the **menstrual** (men'strü əl) **cycle**. The menstrual cycle involves all the hormones that have been discussed and two other organs of the reproductive system, the **Fallopian** (fə lō'pē ən) **tubes** and the **uterus** (yü'tər əs). The events of the menstrual cycle are diagramed in Figure 39–3. It will help to refer to this diagram as the details of the cycle are discussed.

Puberty and sexual maturity can begin in the female anytime between the age of 10 and the midteens. At this time one of the follicles normally matures, or ripens, during every 28-day cycle. During the ripening process the follicle fills with a liquid and swells, and the ovum grows and moves toward the surface of the ovary. The ripening process occurs during the first half of the 28-day cycle. About halfway through the cycle the follicle ruptures and the ovum is released, a process called **ovulation** (ō vyə lā'shən). The ovum falls into the funnellike opening of the Fallopian tube. In the Fallopian tube there is about a 24-h period when the ovum can be penetrated by a sperm. This is the process of **fertilization**.

39–6 Control of the menstrual cycle Hormones are in direct control of all the events of the menstrual cycle. The pituitary hormones, FSH and LH, stimulate development of the follicle and the ovum. As this is occurring, estrogen from the ovaries causes the inner lining of the uterus to thicken and to increase its blood supply. After ovulation the follicle heals and changes into a yellowish body called the **corpus luteum** (kôr'pəs lü'tē əm). The

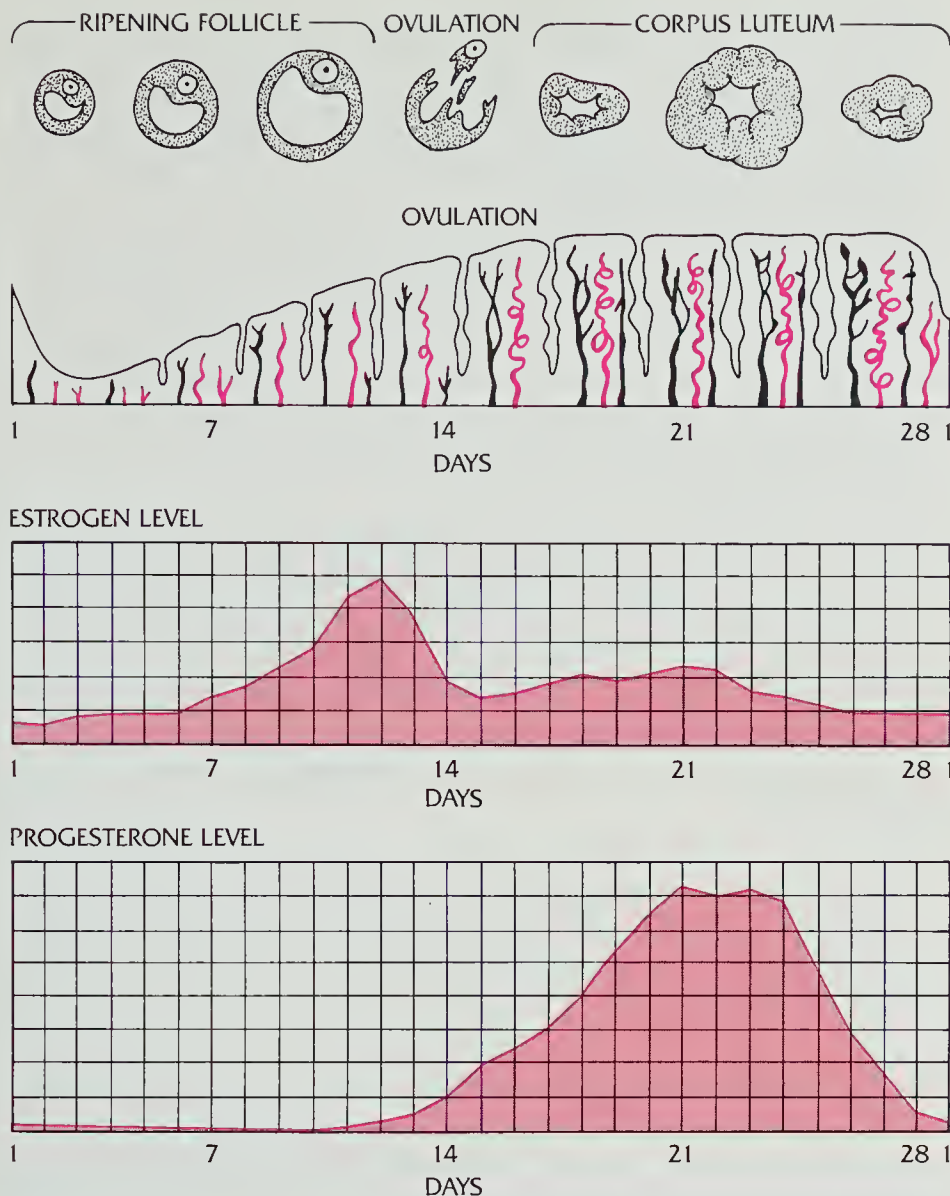


FIGURE 39-3

The events occurring during the menstrual cycle, including changes in hormone levels, are depicted above.

corpus luteum produces the hormone progesterone, which accelerates the development of the uterine lining. If fertilization has occurred, the lining of the uterus is ready to receive the newly developing **embryo** (em'brē ō) within a few days after ovulation.

If fertilization has not occurred, the uterine lining breaks down and is discharged through the vagina. This discharge is mainly a mixture of blood and dead cells. It is released over a 4- to 5-day period called the **menstrual period**.

39-7 Timing the events of the menstrual cycle Now, follow our discussion of the timing of the menstrual cycle with the diagram in Figure 39-3. If ferti-

SCIENCE BACKGROUND

The corpus luteum consists of a yellow mass of liquid and ruptured cells enclosing a blood clot. When it ceases to function, it is replaced by fibrous connective tissue.

The blood loss varies from 20 mL to 200 mL during a menstrual period. Over a reproductive lifetime it is estimated that the female loses 40 L of blood. The loss of just 150 mL of blood is a loss of 75 mg of iron, hence the reason why females sometimes have problems with iron deficiency. The time of the menstrual period is called the *menses*.

SCIENCE BACKGROUND

While studying the timing of the menstrual cycle, it is recommended that students first concentrate on what is going on in the uterus; then concentrate on the hormone changes that affect these events. Basal body temperature usually varies before and after ovulation. After ovulation the basal temperature is from 0.3°C to 0.5°C higher.

MAIN IDEA

The events of the menstrual cycle follow a reasonably consistent timetable.

SCIENCE BACKGROUND

It is not known why only one sperm enters the ovum. Technically the ovum when released is not a gamete since it still carries 46 chromosomes. After ovulation, one polar body is released, which drops the number to 23, but then replication again occurs. Fertilization by a sperm triggers the release of the second polar body.

MAIN IDEA

One sperm fertilizes the egg, normally in the Fallopian tube. Mitosis is slow until the embryo reaches the uterus.

MAIN IDEA

The embryo implants itself by digesting part of the uterine lining. A placenta forms at the junction of the bloodstreams of the mother and the embryo. Food and wastes are passed across the placenta.

SCIENCE BACKGROUND

The cells that begin the process of implantation are called trophoblasts. They secrete proteolytic enzymes that digest the lining.

Several sperm cells can be seen near the edge of the larger egg cell in the photograph at right. Only one sperm will penetrate the egg.

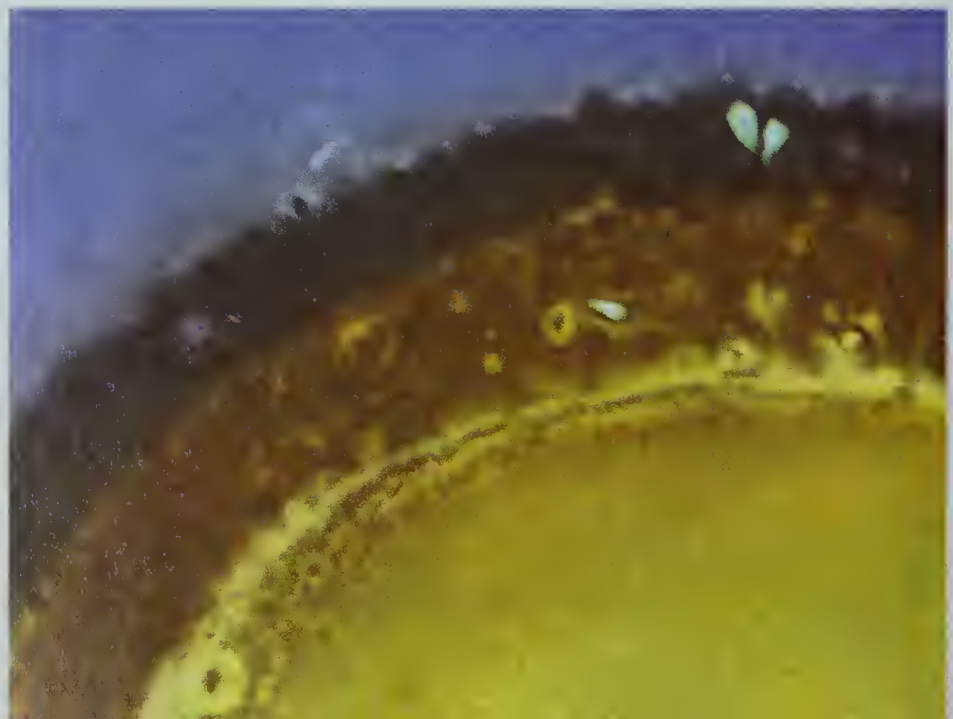
zation has not occurred, the first 4 or 5 days of the cycle is the time of the menstrual period. During this time the follicle is starting to ripen in the ovary. About the seventh day there is an increase in the production of estrogen, which stimulates a thickening of the uterine lining. Ovulation occurs about the fourteenth day.

After ovulation the corpus luteum begins a heavy secretion of progesterone that further stimulates the development of the uterine lining. On the last day of the cycle, if an embryo has not reached the uterus, progesterone secretion suddenly drops. The uterine lining is shed, and this menstrual period begins the second 28-day cycle.

39-8 Fertilization and pregnancy Fertilization normally occurs in the Fallopian tube. Only one sperm can enter the ovum. That sperm will immediately lose its tail. The sperm head, which is primarily the DNA of 23 chromosomes, fuses with the nucleus of the ovum. At this time the nucleus of the ovum also has 23 chromosomes. The resulting cell now has the normal number of 46 chromosomes.

Mitosis, or cell division, does not begin immediately. About 36 h pass before the two-cell stage is reached. After 2 days there are still only eight cells, and after 4 days, only 32 to 64 cells. But then mitosis speeds up as the embryo reaches the uterus.

39-9 Implantation In the uterus some of the cells of the embryo begin the process of **implantation** (im plan tā'shən), the process that attaches the embryo to the wall of the uterus. Some of the embryo cells begin to digest



Overshoot, J.W., Henklee, W.C.: Penetration of the Zona Pellucida of Nonliving Human Oocytes by Human Spermatozoa in Vitro. *Fertil. Steril.* 27:815, 1976. (Reproduced with permission of The American Fertility Society, Publisher.)

part of the uterine lining. This exposes the embryo to a blood supply that nourishes it.

Eventually two membranes develop around the embryo. The outer membrane fuses with the mucosa and forms a **placenta** (plə sen'tə). The placenta is the connection between the bloodstream of the embryo and the mother. Food and wastes are exchanged across the placenta. The inner membrane contains a fluid that cushions the embryo and protects it from injury.

39-10 Hormones of the placenta During pregnancy (preg'nān sē), the period in which the embryo develops, the placenta also produces hormones that are important in maintaining the embryo. The placenta produces **human chorionic gonadotrophin** (kôr ē on'ik gon ə də trof'in), or **HCG**, which prevents the corpus luteum from degenerating for about 3 months. This causes the corpus luteum to continue producing progesterone, which is essential for maintaining the lining of the uterus. Later the placenta takes over the function of producing progesterone.

39-11 Stages of development A 24-day-old human embryo is only about 3 mm long. But it already has a heart that is beating and the beginnings of eyes, a spinal cord, lungs, and digestive organs. At 6 weeks all internal organs are in some stage of development, and the mouth and lips have formed. After 8 weeks the bones begin to form, and at about this time the term **fetus** (fē'tās) is used to describe the developing human. At 18 weeks the fetus is about 15 cm long and is almost completely developed.

During the time of fetal development several changes occur in the female body. The uterus, which normally has a volume capacity of about 3 mL, enlarges to a capacity of 5 to 7 L. The weight of the uterus increases about 30 times. The mammary glands, or breasts, also enlarge. There is a total average mass gain of about 11 kg.

39-12 The birth process After about 280 days from the last menstrual period, the birth process occurs. In this process the smooth muscles in the wall of the uterus begin a series of rhythmic contractions called **labor**. The first labor usually breaks the membrane surrounding the fetus, causing the fluid that has been around the fetus to be released.

After the fluid loss, labor contractions increase in frequency. The opening of the uterus, the **cervix** (sēr'viks),

SCIENCE TERMS

menstrual cycle
Fallopian tubes
uterus
ovulation
fertilization
corpus luteum
embryo
menstrual period
implantation
placenta
pregnancy
human chorionic
gonadotrophin (HCG)
fetus
labor
cervix
afterbirth
lactation
prolactin
oxytocin

MAIN IDEA

Specialized structures have almost completely developed by 18 weeks. During the growth period the uterus increases in volume and weight, and the breasts get larger.

SCIENCE BACKGROUND

Almost any general practitioner has complementary booklets that describe the stages of pregnancy in considerable detail, if students are strongly interested.

MAIN IDEA

Contractions of the uterus and the abdominal muscles force the baby headfirst through the cervix and the vagina. Shortly after birth, contractions expel the afterbirth.

FIGURE 39–4

This is the normal position of the human fetus in the uterus just before the onset of the birth process.

SCIENCE BACKGROUND

About 19 of every 20 births are normal, or headfirst. Breech births, with the buttocks first, sometimes present complications.

ANSWERS TO CHECK YOUR FACTS

1. It fills with liquid and swells, and the ovum grows and moves toward the surface of the ovary. During the first 14 days of the menstrual cycle.
2. The release of the ovum by the follicle. On about the fourteenth day.
3. The corpus luteum. It secretes progesterone.
4. It stimulates development of the lining.
5. The uterus lining breaks down and is discharged through the vagina.

ANSWERS TO REVIEW QUESTIONS

1. The stage of sexual maturation. At about 13. Between 10 and 14.
2. Tubules, epididymis, vas deferens, penis, vagina, Fallopian tube.
3. Lowering of the voice, and growth of body hair in the pubic region, in the underarms, and on the face. Testosterone.
4. In the male, FSH causes tubule development and sperm production. In the female, FSH



Art adaptation by Ethel Gold, reproduced with permission from the BIRTH ATLAS, published and copyrighted by Maternity Center Association, New York.

begins to dilate, or get larger. Labor continues for a variable time, and it is usually longer for the firstborn child. Eventually the labor contractions become rapid. Usually the baby's head is near the cervix, which causes the cervix to dilate more. Strong uterine contractions, along with contractions of the abdominal muscles, finally force the baby out of the uterus and through the vagina. A few minutes later, more contractions of the uterus expel the membranes and the placenta, which are called the **afterbirth** (af'tər bërth).

39–13 Lactation Shortly after birth, two pituitary hormones stimulate the breasts to begin the process of **lactation** (lak tā'shən), or milk production. The hormone **prolactin** (prō lak'tin) stimulates the cells in the breasts to produce milk. The hormone **oxytocin** (ok si tō'sin) stimulates the release of the milk when the breasts are suckled by the baby.

In recent years researchers and children's physicians have gathered some evidence in favor of breast-feeding over bottle-feeding. The protein in human milk is easier to digest than that in cow's milk. The fat in human milk is also easier to digest; human milk includes the enzyme lipase that helps digest the fat. Probably the most important advantage of human milk is the protection it seems to provide against certain early childhood diseases.

CHECK YOUR FACTS

1. Describe the follicle during the ripening process. When does this occur?
2. What is ovulation? When does it happen?
3. What replaces the follicle after ovulation? What does it do?
4. What is the effect of progesterone on the uterus?
5. What happens during the menstrual period?

SUMMARY

The male reproductive system produces sperm and hormones in the testes. In females, ovaries produce ova in the follicles. Sperm are mixed in semen and passed through the penis into the vagina of the female. Puberty in males and females is initiated by hormones from the pituitary. The male hormone testosterone is mainly responsible for the development of secondary sex characteristics. The 28-day menstrual cycle is controlled by hormones.

REVIEW QUESTIONS

1. What is puberty? When does it occur in males? Females?
2. Trace the path of sperm cells from their production to the egg.
3. What are some secondary sex characteristics of the male? What stimulates their development?
4. Compare the effects of the pituitary hormones on the male reproductive system with the effects on the female system.
5. What is the role of estrogen in the female reproductive system?
6. Briefly outline the timing of the events of the menstrual cycle.
7. When does the corpus luteum produce progesterone?
8. What are the functions of the membranes that develop around the embryo after implantation?
9. How does the placenta maintain the lining of the uterus?
10. What are some apparent advantages of breast-feeding over bottle-feeding?

ANALYSIS AND APPLICATION

1. Much has been written in magazines and newspapers about test-tube babies. Do such babies really exist?
2. Why is bottle-feeding versus breast-feeding of babies a debatable issue?

causes the ovaries to grow and produce estrogen, and it stimulates the development of follicles. ICSH causes the interstitial cells to produce male hormones. In females, ICSH causes the same response as FSH except that the ovaries are induced to make progesterone instead of estrogen.

5. Among its many effects, it causes the inner lining of the uterus to thicken and to increase its blood supply.

6. See section 39-7.

7. From the fourteenth through the twenty-eighth day of the menstrual cycle and for about three months after fertilization.

8. The outer membrane forms the placenta which is the site of exchange between mother and embryo. The inner membrane maintains a fluid that cushions the embryo.

9. During the first three months, it secretes HCG, which enables the corpus luteum to continue to produce progesterone, the hormone that maintains the uterine lining. After three months, the placenta itself starts producing progesterone.

10. See section 39-13.

ANSWERS TO ANALYSIS AND APPLICATION

1. Not really. The so-called test-tube babies actually developed normally in a uterus after the egg was fertilized and allowed to develop for two and one-half days outside the body.

2. As more and more women enter the work force and desire an equal role in child care for both father and mother, the question of breast-feeding, which restricts the woman's activities, may fuel and prolong controversy.

40 Drugs, Alcohol,



OBJECTIVES

- To define drugs
- To understand drug dependence
- To explain the effects of narcotic drugs
- To define barbiturates
- To describe the effects of stimulants on the body
- To define psychedelic drugs
- To discuss treatment for drug addicts
- To name the different kinds of alcohol
- To understand that alcohol is a drug
- To describe the effects of alcohol on the body
- To discuss alcohol-related diseases
- To explain that alcoholism is a disease
- To name the components of cigarette smoke
- To describe the effects of smoking on the body

and Tobacco

The Use and Abuse of Drugs

40-1 Drugs A drug is a substance used for the prevention, treatment, or cure of a disease. However, used unwisely without a doctor's advice, drugs can harm the body. According to federal and provincial health and welfare protection agencies, drugs are divided into prescription and non-prescription drugs, narcotic and controlled drugs. Non-prescription drugs, also called over-the-counter drugs, can be sold without a prescription. They are medications that are manufactured for general use. The other drugs are used for specific purposes only and their prescription and use are strictly monitored.

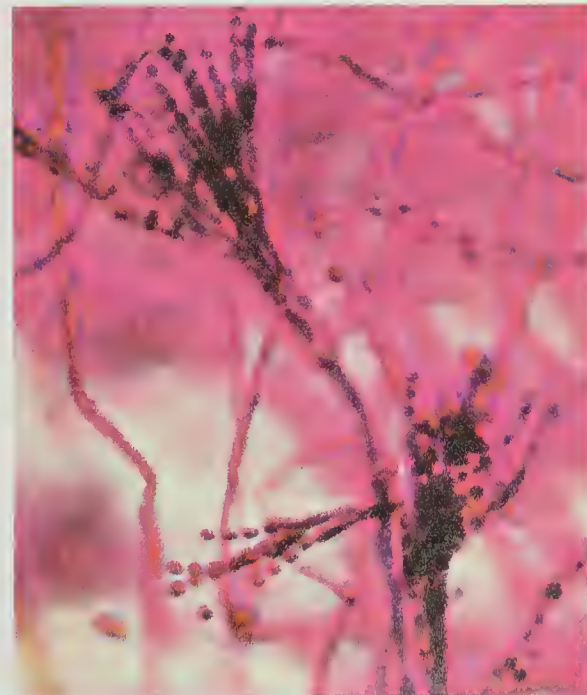
40-2 Sources of drugs Most drugs are synthetic compounds created in drug company laboratories. These drugs are manufactured from chemical elements. Aspirin, sulfa drugs, and sedatives are examples of drugs produced in the laboratory. Other drugs come from plants, animals, and minerals. For example, ground-up hog pancreases are used to make insulin.

40-3 Drug abusers Drug abusers are individuals who self-administer drugs in order to achieve a change of mood or behavior for any number of reasons. Drug abuse often arises out of a desire to escape problems. Drugs may be misused depending on the amount taken and the length of time over which they are taken. Some people misuse drugs by either not reading the directions or by improperly following them. What constitutes the misuse of a drug is often difficult to define. For example, a misuse of a drug

MAIN IDEA

A drug is a substance used for the prevention, treatment, or cure of a disease. However, used unwisely without a doctor's advice, drugs can harm the body.

The drug penicillin, which is effective against many types of bacterial infections, is produced from a fungus called Penicillium.



for some individuals might be considered an abuse for others.

MAIN IDEA

Drug dependence is the psychological and/or physical need for a drug.

40-4 Drug dependence Drug dependence (di pen'dəns) is the psychological and/or physical need for a drug. The continued use of many kinds of drugs results in **psychological** (sī kə loj'ə kəl) **dependence**. The use of the drug becomes habit-forming. One becomes used to the drug and feels the psychological need for it rather than the physical need. Such individuals feel that they could not function without the drug. They have become emotionally dependent on the drug.

Physical dependence can only occur with the use of certain drugs, such as **depressants** (di pres'ənts). This type of dependence is referred to as **addiction** (ə dik'shən). Physical dependence on a drug has occurred if the individual has built up a tolerance to it and if **withdrawal** (wiTH drô'al) **symptoms** occur when the drug is taken away. Withdrawal from a narcotic drug causes aching muscles, chills, fever, stomach cramps, and general body weakness. In some instances withdrawal sickness can cause death.

MAIN IDEA

In this chapter drugs are classified according to their effect on the body, with emphasis on the nervous system.

40-5 Common drug classification In this chapter, drugs are classified according to their effect on the body, with emphasis on the nervous system. We will study the narcotic drugs, sedative drugs, marijuana, stimulants, hallucinogens, and volatile solvents.

MAIN IDEA

Narcotic drugs have a significant effect on the central nervous system. They act mainly as depressants.

40-6 Narcotic drugs **Narcotic** (när kot'ik) **drugs** have a significant effect on the central nervous system. They act mainly as depressants, but they can also relieve pain, coughing, and diarrhea. In very large doses narcotics can produce stupor or even death. If used repeatedly, narcotics may produce physiological as well as psychological dependence. Some individuals who take narcotics experience a feeling of well-being, or euphoria. Others experience the opposite effect of dysphoria, or a feeling of tension, fear, and anxiety.

MAIN IDEA

The opiates are narcotic drugs that are obtained from the oriental poppy plant. Morphine, heroin, and codeine are examples of opiates.

40-7 Opiates The **opiates** (ō'pē āts) are narcotic drugs that are obtained from the oriental poppy plant. **Opium** (ō'pē əm) in crude form can be taken orally or smoked. In some countries smoking of opium has been practiced for thousands of years. **Morphine** (môr'fēn) is a drug derived from opium. Morphine is about 10 times stronger than opium. It is used as a pain killer and has a tranquilizing effect on patients. Drug abusers use mor-



Opium is produced from the poppy plant. Morphine and heroin are derived from opium.

phine orally or by injection. **Heroin** (her'ō in) is a drug made from morphine. It is more addictive than morphine and more than 20 times as strong. Heroin is therefore the most dangerous of the opiate drugs. Its import is outlawed in Canada, even for medicinal purposes.

Codeine (kō'dēn) is another drug derived from opium. However, it does not have strong pain-relieving effects. Codeine is often used in cough preparations. It does not produce as strong a high as the other opiate drugs and is therefore not usually abused.

40–8 Barbiturates Barbiturates (bär bich'ə rāts) are synthetic drugs that act as general depressants or sedatives. They are primarily used in medicine to induce sleep. However, barbiturates can also depress the central nervous system to the point that coma or death may result.

SCIENCE BACKGROUND

Coffee (caffeine) is a natural drug that many of us take into our bodies. Is coffee dangerous to one's health? Recent evidence has indicated that there is no absolute proof that coffee, except in large amounts, causes serious health problems. Coffee has not been shown to be related to heart disease. However, there are some milder symptoms of which people who drink coffee should be aware. Caffeine is a central nervous system stimulant. Therefore, if it is taken in large amounts, it can cause "coffee nerves." Many people who are allergic to the effect of even a small amount of caffeine suffer from "coffee nerves." Stress to students that are drinking too many cola drinks can cause the same reaction. Cola drinks contain caffeine, as do over-the-counter headache remedies.

SCIENCE BACKGROUND

Recent research on animals suggests that some drugs used by pregnant women as treatment for mental illness may cause permanent changes in the brains of their offspring.

MAIN IDEA

Barbiturates are synthetic drugs that act as general depressants or sedatives.

Side effects from taking barbiturates include allergic reactions, hangover, and pain. Continued use of most of these drugs can result in both physical and psychological dependence. Barbiturates are a leading cause of suicide as well as death from accidental poisoning. They become deadly when they are combined with alcohol in the body.

MAIN IDEA

Tranquilizers are drugs that also depress the central nervous system. They are used to calm individuals experiencing emotional stress.

40-9 Tranquilizers **Tranquilizers** (trang'kwə lī zers) are drugs that also depress the central nervous system. They are used to calm individuals and relieve highly emotional states. Some of the most widely used tranquilizers are Miltown and Librium. Users of tranquilizers do not become physically dependent on them, but their continued use can result in psychological dependence.

MAIN IDEA

Marijuana is a drug found in the flowering tops and leaves of the female hemp plant, *Cannabis sativa*. Marijuana is usually classified as a sedative hypnotic.

40-10 Marijuana **Marijuana** (mar ə wä'nə) is a drug found in the flowering tops and leaves of the female Indian hemp plant, *Cannabis sativa*. The drug is made by crushing or chopping the dried leaves and flowers into small pieces. This green product is then usually rolled in short cigarettes or pipes. When smoked, marijuana quickly enters the bloodstream and acts on the brain and nervous system. It affects the user's mood and thinking. Marijuana is usually classified as a sedative hypnotic. Physical dependence does not result from the use of marijuana; however, some people become psychologically dependent on this drug. The drug's effects vary widely, depending on the

While marijuana is not physically addictive, some people may become psychologically dependent on it.





Cocaine is a stimulant drug that is derived from the coca plant. A strong psychological dependence can result from the use of this drug.

SCIENCE BACKGROUND

Studies have shown that marijuana usage can result in errors while driving an automobile. Furthermore, when combined with alcohol it can be very dangerous. In one study, 64 young people were used as subjects. They were first asked to drive through a very complex road course. Then they were asked to drive through the same course after smoking a marijuana cigarette. In almost all cases, drivers did not perform as well after using the drug. All experienced elevation in their heart rate and seemed preoccupied or confused. Many were unaware of pedestrians and the traffic around them.

amount and strength of the marijuana used. The range of effects can vary from depression to a feeling of excitement. However, some users experience no change of mood at all. The long-term effects of the drug are still unknown.

40–11 Stimulants **Stimulants** (stim'yə lents) are substances that speed up the functioning of the body. **Cocaine** (kō kān') is a natural stimulant drug. It is extracted from the leaves of the coca shrub, a plant native to areas of South America. Although cocaine is a stimulant drug, it is listed as a narcotic drug. It is used as a local anesthetic in certain types of surgery. Taken in moderate doses, cocaine tends to speed up the heart, dilate the pupils, and increase body temperature. There is strong psychological dependence among heavy users of the drug.

40–12 Synthetic stimulants **Synthetic** (sin thet'ik) **stimulants** include the **amphetamines** (am fet'ə mēns). These drugs are produced in the laboratory and are used in pep pills. They stimulate the central nervous system and increase the heart rate and breathing rate. Amphetamines are often administered as mood elevators for patients suffering from depression. There is a strong psychological dependence on amphetamines.

MAIN IDEA

Stimulants are substances that speed up the functioning of the body. Cocaine is a natural stimulant drug.

MAIN IDEA

Synthetic stimulants include the amphetamines. These drugs are produced in the laboratory and are used in pep pills.

MAIN IDEA

Hallucinogens are also called the consciousness-expanding or psychedelic drugs. LSD is the most powerful and dangerous hallucinogenic drug.

40-13 Hallucinogens The **hallucinogens** (hə lū'sə nə jens) are also called the consciousness-expanding or psychedelic drugs. LSD, mescaline, and psilocybin are the most common hallucinogenic drugs. Mescaline is produced from peyote, a natural substance found in a certain variety of spineless cactus plant. Psilocybin is also a natural hallucinogen. It is derived from a variety of mushroom native to central Mexico.

LSD is the most powerful and dangerous hallucinogenic drug. LSD, commonly called acid, is odorless, colorless, and tasteless. It dilates the pupils and raises temperature and blood pressure. The senses become distorted, producing strange and unreal responses. For example, some users have reported "hearing" the colors of a painting or "seeing" music in color. The effects of LSD on the user are totally unpredictable. The user does not know if a "trip" (a mental and emotional experience) will be a good one or a bad one. Some users have committed violent acts and others have been hospitalized. Research indicates that LSD can permanently kill brain cells. Scientists believe that LSD can cause birth defects in babies of women who take the drug during pregnancy.

MAIN IDEA

Many products contain substances that can be sniffed to get high.

40-14 Volatile solvents—vapor-sniffing Many products contain substances that can be sniffed to get high. Such products include model glue, paint thinner, gasoline, hair spray, lighter fluid, and kerosene. The vapors from

Although labels usually warn of the dangers involved in inhaling the vapors of volatile substances, some people continue to experiment with this dangerous practice.

SCIENCE TERMS

psychological dependence
physical dependence
depressants
addiction
withdrawal symptoms
narcotic drugs
opiates
tranquilizers
stimulants
hallucinogens





In some cases, heroin addiction is treated with a drug called methadone. Methadone satisfies the body's desire for heroin but is itself habit-forming.

these products are depressants and produce dizziness, sleepiness, loss of consciousness, and hallucinations. Users become light-headed after sniffing these substances. The continued use of these volatile solvents can lead to liver damage, kidney failure, anemia, and death.

40–15 Treatment for drug addicts Most types of treatment that are available to people who are dependent on drugs revolve around counseling and group therapy. Hospital, public, and private facilities exist for the treatment and rehabilitation of drug abusers. In addition, there are therapeutic communities where drug abusers may live together and work out their problems in a group experience.

A synthetic narcotic drug called **methadone** (meth'ə dōn) is used by physicians to treat some cases of addiction. If given a daily oral dose of methadone, a heroin abuser can be "maintained," or stabilized. This drug develops physical dependence, but it satisfies the body's craving for heroin. However, it is important to note that methadone

MAIN IDEA

Most types of treatment that are available to people who are dependent on drugs revolve around counseling and group therapy.

ANSWERS TO CHECK YOUR FACTS

1. Prescription drugs and over-the-counter drugs.
2. An individual who self-administers drugs to achieve a change of mood or behavior for any number of reasons.
3. The psychological and/or physical need for a drug.
4. Narcotic drugs act mainly as depressants.
5. Drugs used to depress the central nervous system.
6. Model glue, paint thinner, gasoline, hair spray, lighter fluid, and kerosene.
7. A synthetic drug used by physicians to treat some cases of addiction.

MAIN IDEA

Ethyl alcohol is the alcohol most often found in beverages. Other alcohols include methyl alcohol and denatured alcohol.

MAIN IDEA

Alcohol acts as a depressant, not a stimulant, to the entire nervous system.

blocks only the effects of heroin. It does not block the effects of other drugs. People who approve of methadone maintenance claim it helps heroin abusers lead a better life. However, those who disapprove of this method feel that dependence has only been shifted from one drug to another.

CHECK YOUR FACTS

1. Name the two classes of drugs.
2. Define a drug abuser.
3. What is drug dependency?
4. Describe the primary effect of narcotic drugs on the body.
5. What are tranquilizers?
6. Can you name several volatile solvents?
7. What is methadone?

The Use and Abuse of Alcohol

40-16 What is alcohol? **Ethyl alcohol** (eth'əl al'kə hōl) is the alcohol most often found in beverages. It is produced by the action of yeast cells on carbohydrates in grain, potatoes, and fruit juices. Another alcohol, **methyl** (meth'əl) **alcohol** is made from wood. This alcohol is found in rubbing alcohol and antifreeze. It is highly poisonous and has no medical uses. Even its fumes are dangerous. **Denatured** (dē nā'chərd) **alcohol** is alcohol rendered unfit for use as a beverage or medicine by adding toxic ingredients. It is used commercially as a solvent.

40-17 Alcohol is a drug Most people never think of alcohol as being a drug. However, alcohol acts as a depressant, not a stimulant, to the entire nervous system. In fact, alcohol used to be used to deaden the pain of operations. Alcohol interferes with the chemical transfer involved in the communications system of the central nervous system. It blocks the transmission of messages from the brain to the rest of the body. Paralysis of the central nervous system results from drinking large quantities of alcohol. The paralysis disappears when the amount of alcohol in the system diminishes.

Alcohol acts immediately upon the brain's higher centers. The drinker experiences a sense of release and elation when these centers are dulled. For example, a shy person may become loud. In addition, muscular coordination is often diminished, and a person's ability to perform tasks requiring skill is reduced.



Cereal grains are the starting materials in the brewing of beer. Fermentation by yeasts on sugars in the grains produces ethyl alcohol.

40-18 What happens to alcohol in the body?

In addition to being a drug, alcohol is also a food. However, it is low in nutritive value and high in caloric value. Alcohol is absorbed rapidly by the body tissues. Because it does not have to be digested, it can enter the blood through the stomach wall or intestine soon after being swallowed. This explains why the effects of alcohol are felt only a few minutes after drinking it. A few minutes after taking a drink, alcohol can be detected in the blood and on the breath. About 20 percent of a drink of alcohol is absorbed from the stomach into the bloodstream. The rest is absorbed through the blood vessels of the small intestine.

MAIN IDEA

Alcohol is absorbed rapidly by the body tissues. The body cells oxidize most of the alcohol and release heat energy from it.

SCIENCE TERMS

ethyl alcohol
methyl alcohol
denatured alcohol
cirrhosis
delirium tremens
Wernicke's syndrome
alcoholism
reaction time

MAIN IDEA

Cirrhosis, or hardening of the liver, is a disease associated with excessive drinking of alcohol. Delirium tremens and Wernicke's syndrome are other alcohol-related diseases.

SCIENCE BACKGROUND

Deaths from cirrhosis of the liver have risen in many urban areas to become the fourth leading cause of death among people between the ages of 25 and 65. The symptoms of cirrhosis include jaundice, sallowness of skin, and loss of appetite. In addition, vomiting of blood may occur in the advanced stages.

MAIN IDEA

Alcoholism is a disease. The exact cause of alcoholism is unknown.

The body cells oxidize most of the alcohol and release heat energy from it. The temperature of the blood is raised and the skin flushes. The drinker feels warm. However, the warmth is only on the surface. There is an enlargement of the capillaries in the skin, and actually the body loses heat in this process.

The oxidation of alcohol occurs in the liver. Alcohol is combined with oxygen and energy is released. Carbon dioxide and water are the waste products of this process. The remainder of the alcohol is removed from the body in a variety of ways. Some is released into the lungs as vapor. Some of the alcohol passes out through the kidneys as a part of urine. In addition, some alcohol leaves the body through the sweat glands of the skin.

40–19 Alcohol related diseases Cirrhosis (sə rō'sis), or hardening of the liver, is a disease associated with excessive drinking of alcohol. In this disease the liver enlarges. It later shrinks and hardens. The liver cells are replaced by scar tissue. Cirrhosis of the liver is six times more common among alcoholics than among the general population.

Delirium tremens (di lir'ē əm tri'mens), or DT's, is a disease of the nervous system occurring in about 5 percent of all alcoholics. Usually DT's occur in individuals who have been excessive and steady drinkers for several years. However, they can also occur after a drinking spree. Some alcoholics have repeated bouts with DT's.

Individuals with DT's have uncontrollable shaking, hallucinations, and convulsions. Because such patients usually have no appetite, have fevers, and sweat excessively, they are fed intravenously large amounts of fluid. Most DT's end after about two days. Nearly 15 percent of all patients suffering from DT's die from circulatory collapse or shock.

Wernicke's syndrome is another alcohol-related disease. Persons afflicted with this disease have paralysis of the eye muscles, a staggered gait, brain hemorrhaging, and poor muscular coordination.

40–20 Alcoholism Alcoholism (al'kə hō liz əm) is a disease. The chronic alcoholic is both an emotionally and physically sick individual. There are approximately 10 million alcoholics in North America. It is interesting to note that alcoholics come from nearly every age group and every walk of life.

The most important warning signal indicating possible alcoholism is that the drinker begins to look at alcohol as if

ALCOHOL IS A DRUG

IT RETARDS YOUR ABILITY
TO REMEMBER
TO REASON
TO UNDERSTAND
TO MAKE DECISIONS

SEE THE ALCOHOL
DAMAGE BRAIN CELLS!



Alcohol affects the normal functioning of the body's systems. Therefore it is a drug.

it were a drug rather than a beverage. The drinker begins to drink to obtain a feeling of release of tension. Another warning sign is that the person drinks more frequently.

The exact cause of alcoholism is unknown. However, some scientists believe that the alcoholic's body is unable to properly metabolize alcohol. Alcoholism has also been linked to an abnormal craving for alcohol by the body and to heredity.

40-21 Alcohol and driving You have probably heard the statement: "If you drive, don't drink; if you drink, don't drive." Combined with driving, alcohol causes thousands of deaths and injuries every year. Over one half of all automobile deaths can be traced to an over-indulgence in alcohol.

SCIENCE BACKGROUND

The National Council on Alcoholism reports that teenagers are beginning to use alcohol earlier than the young people of 20 to 30 years ago. Also, they are getting drunk more frequently. About 90 percent of today's teenagers have tried alcohol. Twenty to 30 years ago, a little over 50 percent had tried it.

MAIN IDEA

Alcohol and driving do not mix. A person who has had a few drinks will show a loss of coordination, concentration, and judgment.

All provinces and territories have strict laws against driving while under the influence of alcohol. A breathalyzer test can be used to determine the percentage of alcohol in a person's blood.



ANSWERS TO CHECK YOUR FACTS

1. Ethyl alcohol, methyl alcohol, and denatured alcohol.
2. Yes. However, it is low in nutritive value and high in caloric value.
3. A disease of the nervous system occurring in about 5 percent of all alcoholics.
4. The drinker looks at alcohol as if it were a drug, rather than a beverage, and drinks more frequently.
5. Alcohol increases one's reaction time.

The main reason why alcohol and driving do not mix is that a person who has had a few drinks will show a loss of coordination, concentration, and judgment. One's **reaction time**, or the time it takes for a muscle to respond to a stimulus, is increased by nearly one-third after two or three drinks.

CHECK YOUR FACTS

1. Can you name several different types of alcohol?
2. Is alcohol a food as well as a drug?
3. What is delirium tremens?
4. What are some warning signs of alcoholism?
5. How is one's reaction time affected by alcohol?

MAIN IDEA

People smoke for a variety of reasons. Many claim it relieves nervous tension.

MAIN IDEA

The harmful ingredients in cigarette smoke include nicotine, carbon monoxide, and tars.

The Use and Misuse of Tobacco

40-22 Why people smoke People smoke for a variety of reasons. Some enjoy the taste or smell of tobacco; others say they smoke to be sociable or that their friends smoke. People also smoke tobacco as a reaction to stress. They claim it relieves nervous tension. However, once a person has started to smoke, smoking becomes a habit that is difficult to break.

40-23 What are the components of cigarette smoke? Some of the harmful ingredients in cigarette smoke include **nicotine** (nik'ə tēn), **carbon monoxide**, and **tars**. Nicotine is a naturally occurring stimulant that is the active ingredient in tobacco. It is a very powerful poison in concentrated form. Nicotine is also used as the

poison in insect spray. A very small amount could kill a person. However, a smoker does not absorb that much nicotine at any one time.

Carbon monoxide is the most dangerous gas in cigarette smoke. This poisonous gas is also found in automobile exhaust. Carbon monoxide lowers the oxygen-carrying capacity of the blood. For the body tissues to receive adequate amounts of oxygen, the heart has to work harder to circulate blood. Cigarette smoke contains about 1 percent of carbon monoxide.

Tobacco tar is made up of chemicals that produce a brown sticky material when condensed from cigarette smoke. Many of the cancer-causing agents, or **carcinogens** (kär sin'ə jens), in cigarette smoke are present in tar. These materials have been laboratory tested on animals and have caused the growth of cancers.

40-24 Effects of cigarette smoking Cigarette smoking affects the circulatory system. Cigarette smoke causes constriction of the small blood vessels. The heart rate increases and the blood pressure rises. This rise in the blood pressure increases the work of the heart by nearly 30 beats per minute. Smoking also promotes hardening of the arteries. The death rate from coronary heart disease among smokers is double that among nonsmokers.

Smoking also causes blood clots within a blood vessel, thus blocking the flow of blood. This condition is called **Buerger's disease**. It often occurs in the feet. Later, gangrene poisoning may set in and require amputation of toes, fingers, arms, or legs.

SCIENCE TERMS

nicotine
carbon monoxide
tars
carcinogens
Buerger's disease
emphysema
bronchitis

MAIN IDEA

Cigarette smoking affects the circulatory system. Cigarette smoke causes constriction of the small blood vessels. The nose, throat, trachea, bronchi, and lungs are also affected by cigarette smoking.

SCIENCE BACKGROUND

Many athletes do not smoke because they feel it affects their performance. One study of 2 000 runners was conducted over several track seasons. It showed that the nonsmokers took first place in competition more often than did the runners who smoked. Some tests of physical steadiness have also shown that nonsmokers are steadier than smokers. Few coaches of high-school and college athletic teams knowingly permit their athletes to smoke.



FIGURE 40-1
The ingredients in tobacco smoke

ANSWERS TO CHECK YOUR FACTS

1. Some people enjoy the taste or smell of tobacco; others smoke to be sociable and to relieve stress.
2. Cigarette smoking causes constriction of the small blood vessels, increases the heart rate, and causes blood clots.
3. Cancer, emphysema, and bronchitis.

MAIN IDEA

Different types of cancers have been linked to heavy cigarette smoking for many years.

The nose, throat, trachea, bronchi, and lungs are affected by cigarette smoke. Gases and particles in cigarette smoke irritate the moist mucous membranes of the respiratory tract. Mucus secretion increases and cilia on the mucous membrane become damaged and cannot function properly. The bronchial tubes are irritated by smoke, causing smokers to cough. The irritating effects of smoking on the throat, lungs, and sinuses are increased by inhaling.

The death rate due to **emphysema** (em fə sē'mə), a disease in which the lungs lose their elasticity, and **bronchitis**, an inflammation of the bronchial tubes, is four times higher among smokers than among nonsmokers.

40–25 Smoking and cancer Different types of cancers have been linked to heavy cigarette smoking for many years. Cancers of the larynx, pharynx, tongue, and lip occur more frequently among smokers. Smoking is a direct cause of lung cancer. It is the most common cause of death due to cancer among North American men. It is also

Research has indicated a link between cigarette smoking and several forms of cancer, including lung cancer. Yet, people continue to smoke.



increasing as a cause of death among North American women. Only 10 percent of all deaths from lung cancer occur in nonsmokers. The obvious way to prevent lung cancer is not to smoke or to stop smoking. Another disease, cancer of the stomach, is 40 percent more common among smokers than among nonsmokers.

CHECK YOUR FACTS

1. Can you name several reasons why people smoke?
2. What are some effects of cigarette smoking on the body?
3. Name some diseases that are directly related to cigarette smoking.

SUMMARY

Drugs can harm the body if they are used unwisely without a doctor's prescription. Drug abusers are individuals who self-administer drugs to achieve a change of mood or behavior for any number of complex reasons. Drug dependence is the psychological and/or physical need for a drug. Alcohol is a drug. It acts as a depressant, not a stimulant, to the nervous system. Organic diseases can result from the excessive use of alcohol. Tobacco is misused for a variety of reasons. Smoking is a contributory factor in many diseases and tends to shorten life.

REVIEW QUESTIONS

1. What are the effects of barbiturates on the body?
2. Can you explain why the hallucinogenic drugs are harmful?
3. How does vapor-sniffing affect the body?
4. Discuss modes of treatment for drug addicts.
5. Explain why alcohol consumption gives one a feeling of warmth.
6. Explain what happens to alcohol in the body.
7. What are the effects of alcohol on the nervous system?
8. What are some possible causes of alcoholism?
9. Describe some of the symptoms of alcohol-related diseases.
10. What are the ingredients of cigarette smoke?

ANALYSIS AND APPLICATION

1. Can you discuss the factors involved in defining whether a drug is being misused or abused?
2. Explain the physiological, psychological, and sociological causes that can lead a person to alcoholism.

ANSWERS TO REVIEW QUESTIONS

1. Barbiturates act as general depressants or sedatives.
2. The effects on the user are totally unpredictable. Some users have become violent.
3. The vapors from these products are depressants and produce dizziness, sleepiness, and loss of consciousness.
4. Most types involve counseling and group therapy.
5. The body cells oxidize most of the alcohol and release heat energy from it. The temperature of the blood is raised and the skin flushes. The drinker feels warm. However, there is an enlargement of the capillaries in the skin and actually the body loses heat.
6. Alcohol is absorbed rapidly by the body tissues. It can enter the blood through the stomach wall or intestines soon after being swallowed.
7. Alcohol acts as a depressant on the nervous system.
8. The exact cause of alcoholism is unknown, but it has been linked to heredity.
9. No appetite, fevers, poor muscular coordination, shaking, hallucinations, convulsions, paralysis of the eye muscles, a staggered gait, brain hemorrhaging.
10. Nicotine, carbon monoxide, and tars.

ANSWERS TO ANALYSIS AND APPLICATION

1. Drugs may be misused or abused depending on the amount taken and the length of time over which they are taken.
2. Alcoholism has been linked to an abnormal craving for alcohol by the body and to heredity. People drink to escape from their problems. They also drink to be sociable.

UNIT 7 REVIEW

1. Discuss the digestion of carbohydrates and proteins in the human digestive system.
2. Prepare a report on the functions of the four types of human teeth.
3. Discuss the functions of red blood cells, white blood cells, and platelets.
4. Prepare a labeled diagram of the heart and the lungs to show the pulmonary circulation. Use arrows to indicate the direction of blood flow.
5. Discuss some of the disorders that can affect the respiratory system.
6. Why is excretion considered to be a homeostatic mechanism?
7. List some of the effects on the body produced by the hormone epinephrine.
8. Discuss the roles of the two hormones produced by the pancreas.
9. Sketch a typical nerve cell and label the main features. With an arrow, indicate the direction of nerve impulse propagation in the sketch.
10. Name the three main regions of the brain and the particular functions of each region.
11. Discuss the basic types of joints and give an example of each type.
12. Describe the structure of striated muscle tissue as revealed by the electron microscope.
13. Prepare a report on how regular exercise affects the muscular system.
14. Discuss the role of hormones in controlling the events of the menstrual cycle.
15. What are some of the health hazards associated with the drinking of alcohol?



Unit 8

ECOLOGY

For many years biologists considered their proper field of study to be the organism and the structures and functions within it. To understand the “secrets” of life was their main goal, and they proceeded as though all life’s secrets were hidden inside organisms, like treasures in a trunk. But that approach was limited. How could a biologist explain the population explosion of a deer herd by studying the insides of deer? Could a biologist always understand the decline of a trout population in a lake by studying the insides of a trout? Such problems took the biologist beyond the individual organism, to the population, to the community, and to the physical environment. This opened up another realm of study, the science of ecology, which is the subject of this last unit.

Investigation 58 from *Laboratory Investigations in Biology* can be done with this chapter.

41 *Population, Community*



OBJECTIVES

- To define a population
- To define a habitat
- To describe the three general habitats: terrestrial, freshwater, and marine
- To explain that population size depends upon four different factors: natality, mortality, emigration, and immigration
- To understand that population size can be graphed by a typical S-curve
- To distinguish between a community and an ecosystem
- To understand the concept of the ecological niche
- To describe the three basic niches in nature

& Ecosystem

41-1 Population A **population** is a group of organisms of one species defined in space and time. An example of a population is all the black walnut trees of York County, Ontario, in August. Such a population is called a local population if the species range extends beyond the described area. This would be the case of the black walnut trees. They are found in other parts of Ontario and in other provinces.

41-2 Habitat Every population has a **habitat**, which is the place where it lives and carries out its activities. For example, the habitat of a local population of raccoons could be a small forest. The habitat of a local population of rainbow trout could be the creek that runs through the forest. A small mountain in southern Alberta could be the habitat of the local population of white pine trees that make up much of the forest.

Many populations, such as those of raccoons, rainbow trout, and white pine trees, have a stable habitat. Except for seasonal changes, their habitat remains nearly the same year after year. Some populations, however, live in habitats that vary throughout the year. A population of mallard ducks may spend the summer in a marsh in Canada and the winter in a bayou of Louisiana. During the spring and fall migrations, their habitat may be a pond one day, a stream the next day, and a lake the day after.

41-3 The general habitats There are three general habitats in which populations live. Those populations that live primarily on land are said to live in a **terrestrial**

MAIN IDEA

A population is a group of organisms of one species defined in space and time.

MAIN IDEA

A habitat is where a population lives and carries out its activities.

The ibex, or wild goat, lives in the mountainous areas of Europe and North Africa. Its food consists entirely of vegetation.





The long spines of the lion-fish are actually modified, poisonous fins. An ocean-dweller, the lion-fish will attack other fishes with these fins.

MAIN IDEA

Population size depends on natality, mortality, emigration, and immigration. Extinction is the death of a population.

SCIENCE BACKGROUND

Students sometimes have difficulty accepting that organisms in swamps, mudholes, and inland bodies of salt water are considered to be freshwater organisms.

(tə res'trē əl) **habitat**. Those that live in the oceans or seas live in a **marine** (mə rēn') **habitat**. Other aquatic populations that do not live in an ocean or sea are said to live in a **freshwater habitat**.

41-4 Population size The size of a population over a period of time depends upon four factors. One factor is **natality** (nā tal'ə tē), or the rate of birth within the population. The second factor is **mortality** (môr tal'ə tē), the rate of death within the population. In some populations these two factors alone will determine the population size. If natality exceeds mortality, the population will grow. If mortality exceeds natality, the size will decrease. If mortality continues to exceed natality, population death can occur. The death of a population is called **extinction** (ek stingk'shən).

The other two factors affecting population size are movements in and out of the population. Outward movements, where the individuals leave the population, are called **emigration** (em ə grā'shən). An example of emigration occurs when a local population, such as a hive of honeybees, reaches a certain size. At that time the queen bee and many others leave and establish a new hive.

The other type of movement is **immigration** (im ə grā'shən), which is a movement into a population. This happens whenever a vegetable or flower garden is planted. At the beginning there are small populations of weeds. These populations always grow because of immigrant seeds that find their way into the garden.

The long-nosed gar is found in the Great Lakes and in many rivers of the eastern United States / Canada. It feeds on other fishes.



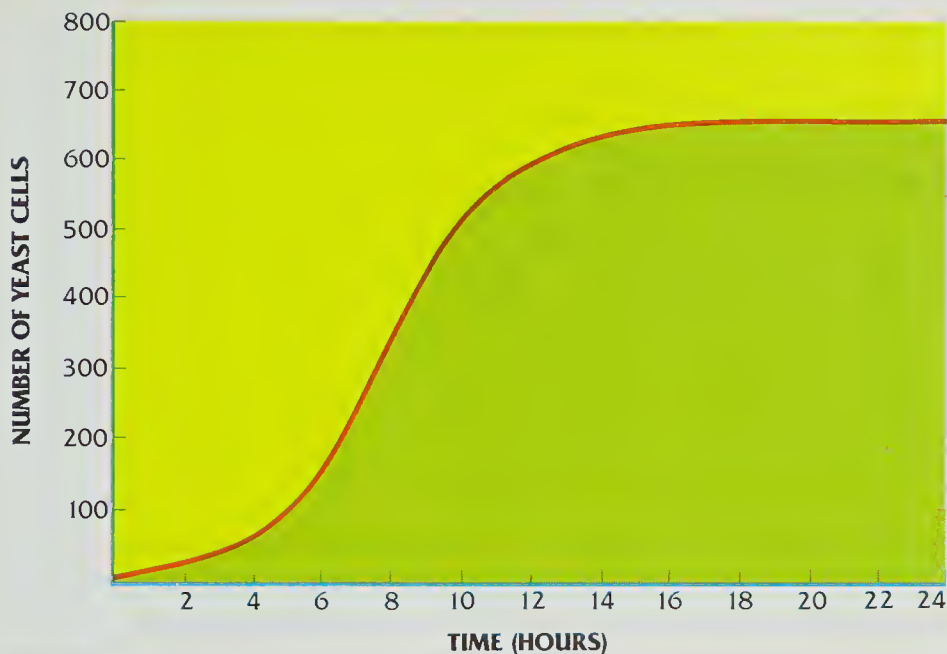


FIGURE 41-1 The S-curve growth pattern in a population of yeasts is graphed above. Limiting factors eventually slow population growth.

SCIENCE BACKGROUND

Technically natality is not necessarily the "birth" rate because individuals are reproduced by other processes such as regeneration and seed development.

41-5 Control of population size Many factors control natality, mortality, emigration, and immigration within a population. Such factors are called **limiting factors**. Limiting factors may include the amount of available space, water, and food. They also may include the effects of other populations. For example, a limiting factor on the mortality of a population of grasshoppers could be the number of bird populations that feed upon them.

Populations often experience a growth pattern that is called an **S-curve pattern**. This may result when a population enters an entirely new habitat. At first the growth of the population is quite slow. When the growth pattern is plotted on a graph, the early phase of growth is a line with a gradual rise.

After the first phase of growth, as natality continues to exceed mortality, the growth rate increases. More and more offspring survive and multiply, with each succeeding generation producing more than the previous one. This increased rate of growth is seen on a graph as a line that gradually becomes more vertical.

Eventually every population encounters more and more limiting factors as its size increases. Typical limiting factors are the lack of space, food, or water. In some populations a limiting factor can be an accumulation of waste products that poisons the individuals. Sometimes it is a disease epidemic that is caused by the crowding. In any case the population growth rate begins to decline. Mortality begins to

MAIN IDEA

Limiting factors usually determine the maximum to which a population can grow, resulting in an S-curve growth pattern.

equal natality, and the slope of the line on the graph begins to level out. The result is a curved line that looks somewhat like the letter S; hence, the name *S-curve*.

MAIN IDEA

A community is a group of populations living in a defined area, or habitat. *Biota* describes all the populations in a community.

SCIENCE BACKGROUND

The term *biomass* also might be introduced at this time. This is a quantitative measure of the biota in a community.

MAIN IDEA

The ecosystem includes the community and its abiotic environment. Ecology is the study of ecosystems.

41–6 The biotic community The **biotic** (bī ot'ik) **community** is a group of populations living in a specific area, or habitat. The term **biota** (bī ō'tə) includes all the populations in a community.

Biotic communities vary in size and in variety of populations. A small community might be the biota in a decaying log. This biota could include populations of termites, ants, beetles, and several species of bacteria and fungi.

Major communities include forests, ponds, and streams, where the biota is mostly independent from that of other communities. Major communities of the same type have similar structures. For example, a pond in England and a pond in Manitoba would have almost the same kind of biota. This biota would be distributed in nearly the same places in the two ponds.

41–7 The ecosystem The **ecosystem** (ē'kə sis tem) is a level of biological organization above that of the community. The ecosystem includes the community and the nonliving environment with which it interacts. The nonliving environment is called the **abiotic** (ā bī ot'ik) environment.

The biotic community of a pond may include animals, such as these leopard frogs, plants, protists, and monerans.



It is important to realize the difference between a community and an ecosystem. A pond community includes only the biota of the pond—the fish, tadpoles, insects, microorganisms, algae, and plants. The ecosystem includes the water, mud, dissolved gases, and chemicals, and the atmosphere over the surface of the pond.

Ecology was defined in Chapter 1 as the study of organisms and their environment. Now we can give it a more precise definition. **Ecology** is the study of ecosystems. This study includes how populations of organisms affect their abiotic environment and how the abiotic environment affects populations of organisms.

41–8 Interaction in the ecosystem Included in the definition of an ecosystem is the term *interact*. This means “to act upon each other,” and it refers to the way the biota and abiotic components act upon each other. For example, the biota of a pond acts upon and changes the abiotic components. The pond biota is constantly releasing wastes, such as urea and carbon dioxide, into the water. Much of the biota removes dissolved oxygen from the water and uses it in transforming energy.

The abiotic components also act upon the biota. For example, in Manitoba the winter temperature of the atmosphere above the pond drops below freezing. This converts the water above the biota to ice and drops the temperature of the rest of the water. In turn, this causes some of the biota, such as turtles and frogs, to burrow into the mud. It also causes the death of many plants and a slowdown in the swimming and feeding activities of the fish.

In ecosystems not affected by human activities, the interaction between the biota and the abiotic environment is usually in some degree of balance. This is a type of **homeostasis**, which is a steady state that we also find within the internal environment of organisms. For example, in a pond a fairly uniform quantity of dissolved oxygen and carbon dioxide is maintained. This balance is partly the result of plants giving off oxygen during photosynthesis and animals giving off carbon dioxide through breathing. Another type of homeostasis exists in the size of the populations. There is usually a balance between natality, mortality, emigration, and immigration. This balance helps to keep the populations about the same size year after year.

41–9 The ecological niche The habitat of a population is the place where it lives. Now we must introduce a broader term, which includes the habitat. The **ecological niche** (nich), or, simply, **niche**, is a population’s com-

SCIENCE BACKGROUND

Ecosystem is a shortened version of *ecological system*, which was introduced by the British ecologist A. G. Tansley in 1935.

MAIN IDEA

Abiotic components and the biota interact in an ecosystem. Normally this interaction is balanced—a condition called homeostasis.

SCIENCE BACKGROUND

The classic closed aquarium is an excellent example of long-term community homeostasis.

MAIN IDEA

A niche is a population’s complete role in an ecosystem. It includes the total impact of a population within the ecosystem in which it lives.

The activities of any population of organisms, such as a beaver population, will affect all other populations in the community.

SCIENCE BACKGROUND

The ecological niche is a very useful concept but extremely difficult to define precisely and even more difficult to evaluate in totality. There are an infinite number of biological characteristics and physical parameters that are involved. Five ants can be crawling on a tree, and each affects the other, but such influences are difficult to quantify for the niche of either. Our approach in the chapter is to give various characteristics of the niche, with examples, so that the intuitive idea will become a working part of the student's background.



plete role in an ecosystem. This role involves many actions and interactions, which we can demonstrate with an example.

Let us use the example of a beaver population to illustrate one niche in an ecosystem. The niche includes the habitat. The population of beavers lives along a creek in lodges they have built. The niche also includes all the activities of the population. These activities include the cutting down of trees, the building of dams and lodges, mating, the raising of their young, and avoiding the lynx and wolverines that prey on them. The niche includes the many ways in which the population affects other populations. The beavers eat the bark from young trees. They cut down hundreds of other trees over a year's time. Their dams create ponds that are a better habitat for fish and plants than the creek itself. The niche includes the effects of a population upon the abiotic environment. The beaver dams change the way the creek flows. Their ponds increase the average water temperature of the creek. By slowing the movement of the creek, the population causes a slowdown of erosion and a decrease in the oxygen supply of the water.

In summary, the niche includes a population's total impact within the ecosystem in which it lives. This impact includes the space required for living, and all the interactions with other populations and the abiotic environment.

SCIENCE BACKGROUND

A bonus product of producers is oxygen, which constantly replaces that which is used from the atmosphere. The unique role of phytoplankton in marine and fresh waters will be discussed in Chapters 45 and 46.

MAIN IDEA

Producers are organisms that transform light energy into food molecules by the process of photosynthesis.

41-10 Producers All ecosystems have three basic niches that are occupied by different organisms. The most basic niche is that of the **producer**. A producer is any or-

ganism or population that has the ability to transform light energy from the sun by photosynthesis. The energy from sunlight is transformed by producers mainly into the bonds of carbohydrates, fats, and proteins. In turn, when the producers are eaten, this energy becomes available to all other populations in the ecosystem.

The producers include all the various kinds of algae and a few bacteria. Producers also include all the green plants.

41-11 Consumers The second basic niche in ecosystems is that of the **consumer**. The consumer is an organism or population that obtains its food and energy directly or indirectly from a producer. Quail and deer are consumers that feed directly upon producers and their products. Such consumers are called first-order consumers. A robin that eats a grasshopper that feeds on plants would be a second-order consumer. Indirectly, through the grasshopper, the robin is obtaining from the plant the energy that originally came from the sun. The robin is obtaining food molecules that were simply rearranged by the grasshopper after eating the plant. In many ecosystems there are third-order, fourth-order, and even fifth-order consumers that simply extend the robin-grasshopper relationship. For example, snakes eat some birds, while eagles and hawks eat snakes.

41-12 Decomposers The third basic niche in ecosystems is that of the **decomposer** (dē kəm pō'zər). The role of the decomposer is to break down dead matter, such as the bodies of plants and animals. Decomposers are found mostly in soil and in the mud at the bottom of oceans and bodies of fresh water. The decomposers include bacteria and fungi, many of which are seldom

SCIENCE TERMS

population
habitat
terrestrial habitat
marine habitat
freshwater habitat
natality
mortality
extinction
emigration
immigration
limiting factors
S-curve pattern
biotic community
biota
ecosystem
abiotic
ecology
ecological niche
producer
consumer
decomposer

MAIN IDEA

The third basic niche is that of the decomposer. The role of decomposers is to break down dead matter and thus make nutrients available for other organisms.

Wapiti, or elk, are first-order consumers that inhabit the western United States and Canada. A population usually has summer and winter ranges.



Fungi, such as these mushrooms, are decomposers. By releasing material locked up in dead organisms, decomposers help recycle these materials.

ANSWERS TO CHECK YOUR FACTS

1. A group of organisms of a species defined in space and time.
2. A place where an organism or a population lives.
3. A terrestrial habitat is largely land, and a freshwater habitat is a body of fresh water.
4. Natality, mortality, immigration, and emigration.
5. See section 41–4.
6. Living space, food supplies, wastes, and population size.

ANSWERS TO REVIEW QUESTIONS

1. All populations living together in a specific habitat.
2. The kinds of organisms, numbers of each kind, the habitat.
3. The structure of each major community is unique for that type and is the same no matter where the community is located.
4. *Ecology* is the study of organisms and their environment and how they affect each other.
5. In general the biota change the conditions of the abiotic environment, and the abiotic environment determines what biota can exist there.
6. It is the balance gained between biotic and abiotic environments of an ecosystem in which humans do not interfere.
7. It is the stable population size achieved when the rates of natality, mortality, emigration, immigration offset each other.
8. A habitat is where an organism lives, and a niche is how it lives in that habitat.
9. A producer can make its own food from the energy of the sun and the raw materials in the envi-



observed except by biologists with high-powered microscopes. But their role is extremely important. Their decomposition activities unlock nutrients that have been tied up in organisms. They release those nutrients and make them available for organisms that are alive and need them.

CHECK YOUR FACTS

1. What is a population?
2. What is a habitat?
3. What is the difference between a terrestrial habitat and a freshwater habitat?
4. What four factors determine the size of a population over a time period?
5. How do these four factors alter the population size?
6. What are some limiting factors that affect population size?

SUMMARY

A population is a group of organisms of one species defined in space and time. A local population may exist if the species range extends beyond the described area. A habitat is where a population lives. Land habitats are called terrestrial habitats. Ocean habitats are called marine habitats. Freshwater habitats are water habitats that are not in an ocean or sea. The size of a population is determined over time by natality and mortality, or birth and death rates. Ecology is the study of ecosystems. The total impact of a population within the ecosystem in which it lives is called the niche of that population. The three basic niches in nearly all ecosystems are producers, consumers, and decomposers.

REVIEW QUESTIONS

1. What is a biotic community?
2. In what ways can communities vary?
3. What characteristics do major communities of the same type, such as pond communities, have in common regardless of geographic location?
4. What is *ecology*?
5. What interactions are there in an ecosystem?
6. Explain homeostasis in an ecosystem.
7. What is homeostasis in a population?
8. How do ecological niches and habitats differ?
9. How does a producer differ from a consumer?
10. What is the niche of a decomposer?

ANALYSIS AND APPLICATION

1. On a warm fall day in the country, a man is seen sitting outside his cabin. He looks out on a quiet pond that sits near him in the pine woods. At night, deer can be seen browsing in the shrubs and herbs nearby, and during the day, ducks are seen swimming and feeding in the pond. What parts of this scene represent
 - a. populations?
 - b. habitats?
 - c. niche?
 - d. producers?
 - e. consumers?
 - f. abiotic environment?
 - g. biotic environment?
 - h. community?
 - i. ecosystem?
2. Construct and describe an imaginary ecosystem. Include at least two producers and four consumers.
3. Observe the area surrounding your school.
 - a. What producers are in the community? This can be answered by naming species or by using such terms as *trees*, *herbs*, *shrubs*.
 - b. Are the producers abundant or are they rare? This may be answered in general terms, or you may give density figures.
 - c. If there are different groups of producers, which group seems to contribute the most to food production?
 - d. Are there layers of producers?
 - e. What consumers are in the community?
 - f. Which consumer orders are represented in the community (first, second, and so on)?
 - g. How many niches can you describe?

ronment; a consumer cannot.
10. A decomposer consumes all dead material for its energy source and releases the materials tied up in dead organisms.

ANSWERS TO ANALYSIS AND APPLICATION

1. (a) Deer, ducks, man, shrubs, herbs, pines. (b) Pine woods, pond, cabin. (c) Deer eating shrubs and herbs at night; ducks swimming and feeding in the pond by day; man sitting and watching from his cabin. (d) Herbs, pines, shrubs. (e) Deer, ducks, man. (f) Warm fall day in the country; land habitat; pond habitat; cabin. (g) All producers and consumers. (h) Pond organisms and ducks; pine woods, deer, man, shrubs and herbs. (i) The two communities, pond and terrestrial; the abiotic environment; and the interactions mentioned between these.
2. The ecosystem should include the physical environment; its substrate; and thermal, water, air, and weather conditions. There should be producers, first-order consumers, and decomposers as a minimum biotic community. The interaction of the parts of the ecosystem should be described.
3. (a) Species names or terms will vary, depending upon the environment. (b) General terms or density figures will vary. (c) Answers will vary with the environment. (d) Attention should be given to differentiating different kinds of producers in a single layer, such as a lawn, then in different layers, such as herbs versus grasses, grasses versus shrubs, and so on. (e) Evidence of the existence of consumers should be given, even though the consumers may not be present at the moment of observation. (f) Several orders should be represented. (g) Note the variety of niches possible.

Investigations 59–60 from *Laboratory Investigations in Biology* can be done with this chapter

42

Patterns of



OBJECTIVES

- To understand that every population is dependent upon some other population for nutrition, shelter, or reproduction
- To appreciate that all energy for life originates in the sun
- To explain the concept of the food chain and food web
- To appreciate that each trophic level involves a loss of energy in the ecosystem
- To describe the two types of food chains
- To understand the various kinds of symbiotic relationships

Dependency

42-1 The web of life With few exceptions, no single population can live alone. Almost every population is dependent upon other populations for food, shelter, or reproduction. This is one of the most important concepts in ecology. All life is like a web, with every population linked to every other population in some way. We shall discuss the nature of some of these dependency links.

42-2 The flow of energy The energy for life originates in the sun in the form of radiant energy. Radiant energy strikes the earth and is trapped by chlorophyll in the cells of producers. The radiant energy is transformed into chemical energy that is used by the producers. But some of that energy continues to flow through the community. It flows to the consumers and decomposers that either eat the producers or decompose their dead bodies.

42-3 Food chains and webs A simplified way of explaining the energy flow in a community is with the **food chain**. The food chain describes who may eat whom in a community. In a grassland community, a food chain might consist of three populations: the grass, pronghorn antelope, and wolf. Or it might consist of as many as five populations: grass, beetle, bird, snake, and eagle.

Each level in a food chain is called a **trophic** (trof'ik) **level**. The trophic level for any one population does not always remain the same. For example, the fox, which is normally a **carnivore**, or meat eater, sometimes eats berries. Part of the time the fox is a **herbivore** (hèr'bā vôr), or plant eater, and occupies a different trophic level.

MAIN IDEA

Almost every population is dependent upon other populations for nutrients, shelter, or reproduction.

MAIN IDEA

Radiant energy is converted to chemical energy during photosynthesis. This energy flows through the community.

The red squirrel is found throughout the forests of North America. It usually feeds on seeds and fruits but birds are included in its diet.



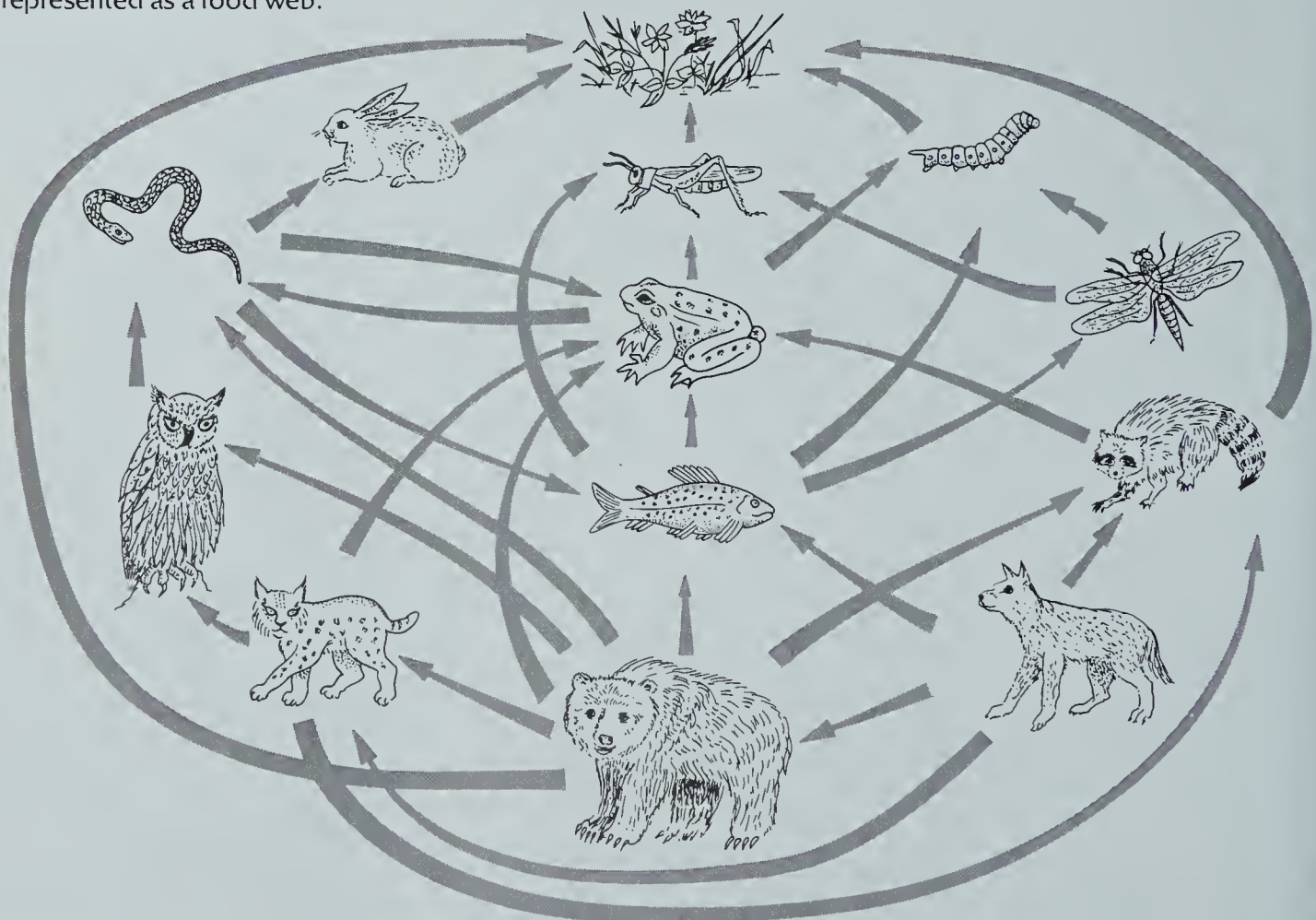


FIGURE 42-1 An example of a simple food chain—plants are eaten by a deer, which in turn may fall prey to wolves.

FIGURE 42-2

The actual relationships between producers and a variety of consumers are very complex. These relationships may be represented as a food web.

A better way of describing who may eat whom in a community is with the **food web**. The food web shows that the energy flow is variable, with animals eating a variety of other animals.





This red fox has caught a ground squirrel for its dinner. The fox includes a variety of small animals and also plant matter in its diet.

42-4 Energy loss in the community As energy flows through the community there is an energy loss at each trophic level. Much of this loss is in the form of heat, which is lost when food molecules are broken down in the cells.

There would be less energy loss in the community if only herbivores fed on the producers. The loss in this first trophic level is estimated to be anywhere from 80 to 90 percent. If the energy flow continues through the second trophic level, through a carnivore, there is an additional

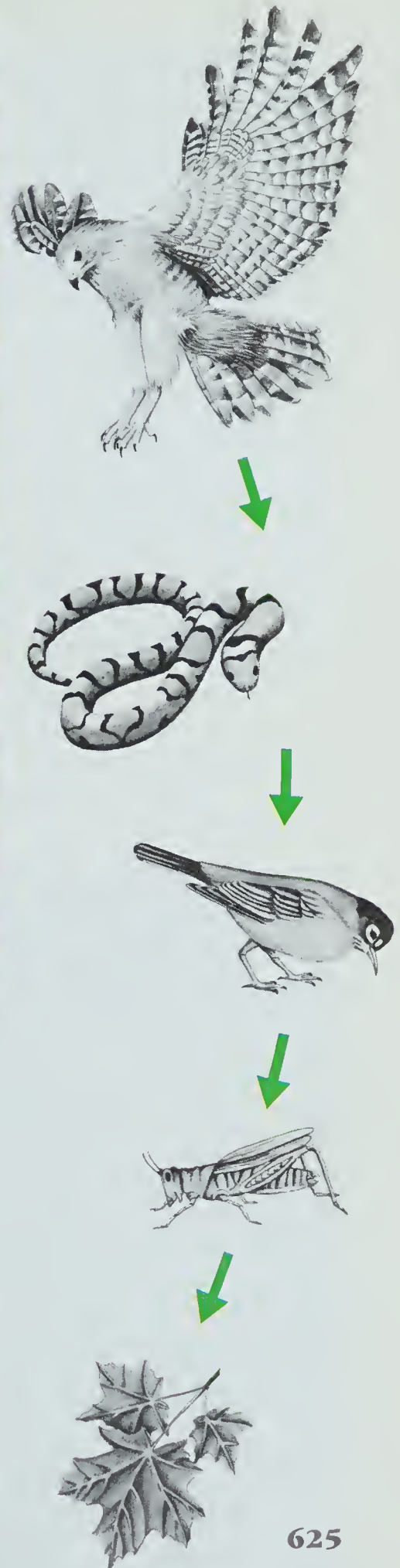


FIGURE 42-3

A food chain, consisting of a producer and four levels of consumers

SCIENCE BACKGROUND

The percentage of transfer of energy from one trophic level to the next is called *ecological efficiency*. The efficiency varies considerably, but the figure of 10 to 20 percent (or a loss of 80 to 90 percent, as quoted in the text) comes from *Fundamentals of Ecology*, 3rd ed., by Eugene P. Odum (Philadelphia: W. G. Saunders Company, 1971), p. 63.

Relating to the problem of feeding an exploding human population, the energy efficiency is greater when herbivorous fish, such as carp, are grown rather than fish that are farther along in the food chain, such as bass.

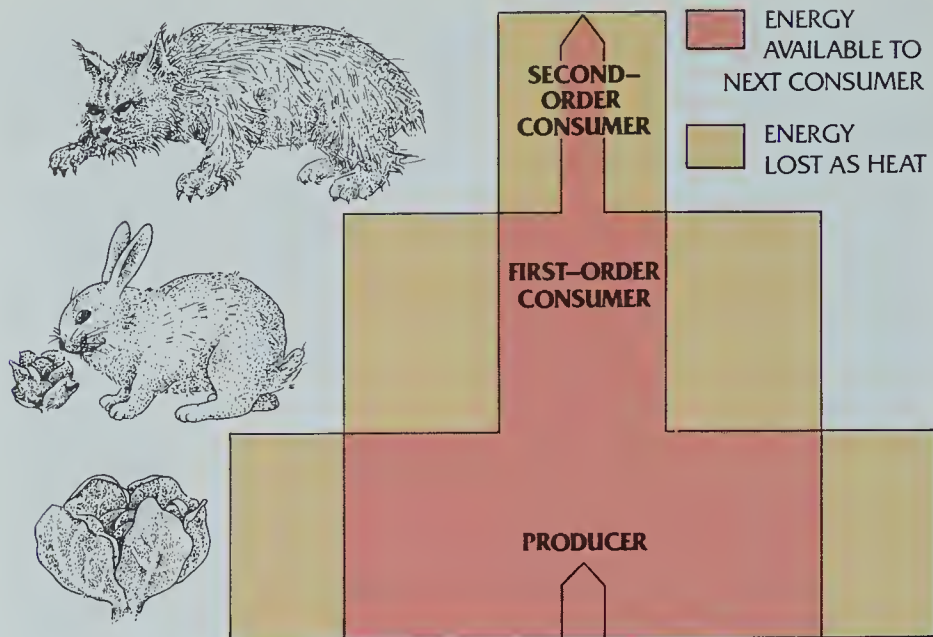


FIGURE 42-4 As can be seen from this diagram, the amount of available energy decreases at each higher trophic level in a food chain.

energy loss of 80 to 90 percent. If the energy continues to flow through more carnivores, two things happen. One, there is a continued energy loss. Two, a limit is reached on the length of the food chain. A diagram that shows energy loss through trophic levels is called an **ecological pyramid** (ek ə loj'ə kəl pir'ə mid).

The preceding discussion has an important lesson for humans. The human population is exploding in many parts of the world. Ecologists predict that more and more people will starve in the years ahead. To help solve this problem, the human food chain must be kept as short as possible. When humans eat grains and other plant products, there is only the loss of energy at the first trophic level. If humans eat animal products, such as beef, chicken, and pork, the loss in energy is doubled by moving through two trophic levels.

MAIN IDEA

In a grazing food chain, consumers eat producers. In a detritus food chain, decomposers eat dead organisms. Most plant matter passes through the detritus food chain.

42-5 Two kinds of food chains There are two basic kinds of food chains in communities. The first is the **grazing** (grā'zing) **food chain**, which is the type that we have already mentioned. In the grazing food chain, the herbivore, or grazer, eats the producer. Then the grazer may be a dinner for carnivores.

The second kind of food chain is the **detritus** (di trī'təs) **food chain**. **Detritus** is the general term for any dead plant or animal matter that is in the process of being decomposed. A forest community is a good place to find a

detritus food chain. Only about 10 percent of the plant matter produced by a forest is eaten by grazers. Most of the grazers are small insects. The other 90 percent ends up mostly as leaves and twigs on the ground. That is when the detritus eaters go to work. Some are bacteria and fungi that we mentioned earlier as decomposers. But there are numerous other populations, such as millipedes, earthworms, beetles, and crickets, that feed on the detritus. They, in turn, end up as a meat dinner for various carnivores, such as birds, lizards, and salamanders.

42-6 Symbiosis Some organisms have a very close physical relationship. This relationship is called **symbiosis** (sim bī ō'sis) and literally means "living together."

There are various kinds of symbiotic relationships. At one time, symbiosis was considered to be only the kind of relationship where all members received benefit from the association. The modern view is that symbiotic relationships may or may not be a benefit to any or all members.

42-7 Parasitism One type of symbiotic relationship is called **parasitism** (par'ə sī tiz əm). In this relationship one organism is the **parasite** (par'ə sīt), the other is the **host**. The parasite lives on or in the host, from which it obtains part or all of its nourishment.

SCIENCE BACKGROUND

If possible, scoop up a container of forest litter, then spread it out over newspapers in the lab to see the kinds of creatures that are in detritus food chains.

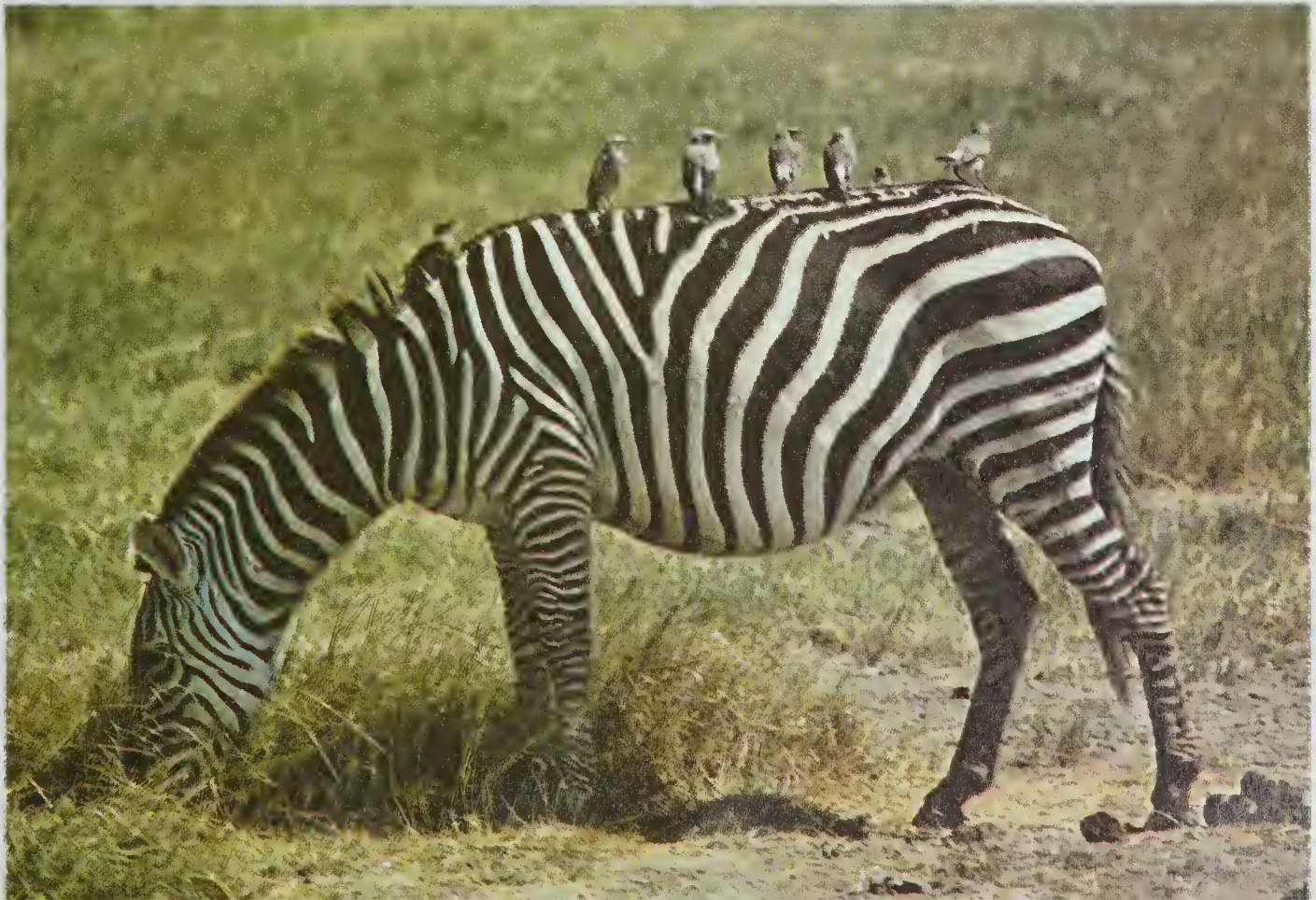
MAIN IDEA

A very close physical relationship between organisms is called symbiosis. These relationships need not benefit any or all members.

MAIN IDEA

A parasite obtains part or all of its nourishment from its host organism.

The tick birds eat insect parasites that live on the skin of the zebra. The relationship between the birds and the zebra is symbiotic.



MAIN IDEA

Commensalism is a relationship in which one member benefits but the other member is unaffected. This occurs between motile marine organisms that seek shelter in the body cavities of sessile organisms.

We have already discussed several kinds of parasites in different chapters of the text. Many groups of plants and most groups of animals include some members that are parasites. They include certain bacteria, protozoans, flatworms, roundworms, segmented worms, and a host of different arthropods.

42-8 Commensalism One of the simplest of the symbiotic relationships occurs when one organism benefits from a relationship and the other is not affected. Such a relationship is called **commensalism** (kə men'sə liz əm).

The anemone fish swims among the tentacles of sea anemones, eating scraps from the food captured by the sea anemones.



Commensalism is common in marine communities. Usually the relationship exists between a sessile (stationary) plant or animal and others that are mobile. For example, most sponges have a variety of small organisms in the cavities of their body. The sponge gets no benefit, but the other organisms obtain shelter and protection from predators. Another example is the small fishes that swim among the tentacles of sea anemones and obtain surplus scraps of food. There is no indication that the anemone benefits from the relationship.

42-9 Protocooperation A step beyond commensalism is the type of symbiosis where both parties benefit but the association is not essential. This kind of symbiotic relationship is called **protocooperation** (prō tō kō op ə rā'shən).

An example of protocooperation is the common relationship between crabs and coelenterates, such as the sea anemone. The sea anemone grows on the back of the crab. This benefits the crab because the anemone provides camouflage, which makes it difficult for predators to see the crab. Also the anemone provides protection because other animals will avoid its tentacles, which have stinging cells. In turn, the anemone benefits by being transported about and provided with part of the food that the crab captures.

42-10 Mutualism In the most dependent kind of relationship, each party depends completely upon the other for its survival. This kind of symbiotic relationship is called **mutualism** (myü'chü ə liz əm) or **obligate** (ob' lə gāt) **symbiosis**.

In an earlier chapter we mentioned the mutualism that exists between termites and the protozoans in their intestine. The protozoans break down cellulose for the termites, and the termites provide food and shelter for the protozoans. Experiments have demonstrated that termites will starve to death on a wood diet without the protozoans.

Another example of mutualism is the relationship between certain plants and **mycorrhizae** (mī kə rī'zē), which are fungi that grow on the roots. Many trees, when transplanted to a different region, will not grow unless mycorrhizae are also transplanted. But then, with the mycorrhizae on their roots, the trees may grow in soil so poor that crops such as corn and wheat cannot survive. The explanation is that the mycorrhizae use their unique enzymes to provide minerals that would otherwise not be available. In turn, the trees provide for the mycorrhizae food that they make in their leaves.

SCIENCE TERMS

food chain
 trophic level
 herbivore
 food web
 ecological pyramid
 grazing food chain
 detritus food chain
 detritus
 symbiosis
 parasitism
 commensalism
 protocooperation
 mutualism
 obligate symbiosis
 mycorrhizae
 lichen

MAIN IDEA

Complete dependency between organisms is called *mutualism*. A lichen is a mutualistic relationship between an alga and a fungus.

SCIENCE BACKGROUND

Protocooperation may be a new term for teachers. The term was coined by W. C. Allee, who studied and wrote about the subject. "Mutualism as obligate symbiosis" is Odum's definition (ibid., p. 229), but other authors do not mention *protocooperation*, and under the category of *mutualism* they include relationships that are mutually helpful but less than obligate.

ANSWERS TO CHECK YOUR FACTS

1. They are dependent on each other for food, nutrients, or shelter.
2. Sunlight energy is changed to chemical energy by producers, and we then eat producers or other consumers to obtain this energy that comes from the sun.
3. Sunlight energy enters the community by the photosynthesis of producers. Energy is passed along to each consumer that eats a producer and is then passed on to the next order of consumers. Thus the chain of organisms used for food is the path that energy follows in the community.
4. In a food web all the eater-eaten combinations are linked together rather than arranged as a simple chain of eaters.
5. It is a producer or consumer level of a food chain.

ANSWERS TO REVIEW QUESTIONS

1. Less biomass, or organisms, are found at the top of the food pyramid than at its base. Producers are always greatest in number, or biomass.
2. It is a diagram that shows the decreasing amount of energy and therefore number of organisms at each higher trophic level.
3. In the grazing food chain, a herbivore eats a producer and is then eaten by a consumer that may be prey for another



A lichen consists of an algae and a fungus in a mutualistic relationship. The two organisms are actually classified as one species.

There is one type of mutualistic relationship in which the two organisms are classified as one species. This is the relationship between fungi and algae in the structure called a **lichen** (lī'kən). The fungi protect the algal cells and hold moisture for them. The algal cells provide food by photosynthesis. The two components of a lichen have been cultured separately in the laboratory. But they are so interdependent, they cannot live on their own in nature.

CHECK YOUR FACTS

1. What relationships link populations to form a web of life?
2. How can we say that the energy that we run our bodies with comes from the sun?
3. How does the idea of a food chain explain the flow of energy in a community?
4. How does a food web differ from a food chain?
5. What is a trophic level?

SUMMARY

One of the most important concepts in ecology is that all populations, with few exceptions, are dependent upon other populations. Chemical energy, originally obtained from radiant energy from the sun, is said to flow through a community. Food chains and food webs trace the path of this flow from organism to organism. Each level in a food chain is called a trophic level. As energy flows through each trophic level, energy is lost from the community. The longer the food chain, the more energy is lost. An ecological pyramid illustrates this loss.

REVIEW QUESTIONS

1. How does the number of organisms at the top of a food pyramid compare with the number at the bottom?
2. What is an ecological pyramid?
3. Describe two kinds of food chains.
4. What is detritus?
5. What is a symbiotic relationship?
6. What is a parasite?
7. What is commensalism?
8. What is protocooperation?
9. What is mutualism?
10. What type of relationship do lichens typify?

ANALYSIS AND APPLICATION

1. Your seven-year-old brother has brought his favorite geranium plant home from school, and he wants to keep it forever. He plans to put the pot in a sunny window and water it. Explain to him that this will not be enough to keep it alive forever, and tell him what else he must do.
2. Often birds can be seen sitting and pecking at the coats of cattle. They remove insects from the coats of the cattle. What kind of symbiotic relationship is this?
3. How might parasitic organisms be considered beneficial to humans?

consumer or carnivore. In the detritus chain, the herbivores and higher consumers eat dead organic matter, releasing raw materials that had been locked in.

4. The dead plant and animal material in a community that is in the process of being decomposed.

5. It is one in which organisms live in very close physical contact.

6. A parasite lives in or on a host organism and obtains nourishment from its host.

7. The symbiotic relationship in which one of the organisms benefits and the other is unaffected.

8. The symbiotic relationship in which both organisms cooperate and benefit, but the association is not essential.

9. The symbiotic relationship in which both organisms depend on each other for survival.

10. The algae and fungi in lichens are mutually related. They cannot survive without each other.

ANSWERS TO ANALYSIS AND APPLICATION

1. Even producers need a constant source of nutrients. After awhile the geranium will use up the supply of nutrients in the soil, and more must be added.

2. It is protocooperation. The cattle are freed of the pests in their coat and the birds are fed. However, the pests may not be damaging to the cattle, and the birds may have an alternate food source; therefore this cooperation is not necessary for the survival of either.

3. In the control of pest populations, parasites may be introduced to eat and destroy a pest that is ruining a crop.

43 *Ecological*



Cycles

OBJECTIVES

- To explain that an ecological cycle is the circular movement of elements or compounds between the biota and the physical environment.
- To understand the oxygen cycle
- To understand the carbon cycle
- To appreciate the possibility that an increase in carbon dioxide in the atmosphere could lead to a warming trend on the earth
- To understand the nitrogen cycle
- To explain that nitrogen fertilizers are essential for the growth of food
- To understand the water cycle and the phenomenon of acid rain

Ecological Cycles

43-1 The ecological cycle A cycle is the movement of something in a circular pattern. An **ecological cycle** is the circular movement of elements or compounds between the biota and the physical environment. In an ecological cycle some element or compound spends part of its time locked up inside an organism's body. Then it may be released to the environment during the organism's lifetime, or it may be returned to the environment after the organism's death by the action of decomposers. In this chapter we shall discuss four of the most important ecological cycles and their variations.

43-2 The oxygen cycle About 21 percent of the atmosphere is made up of oxygen. Ecologists think that practically all of this oxygen is of biological origin. They think it has built up in the atmosphere since the time when photosynthetic organisms first began releasing oxygen as a by-product. Partial evidence for this belief is the fact that anaerobic bacteria are poisoned by oxygen. They can live only in oxygen-free habitats. Certain blue-green algae have special cells that protect key enzymes from oxygen poisoning.

The **oxygen cycle** involves the movement of oxygen back and forth between the atmosphere and the biota. Producers break down water molecules during photosynthesis and release molecular oxygen to the atmosphere. Almost all organisms take oxygen from the atmosphere and use it in cellular respiration. The oxygen functions in the

MAIN IDEA

An ecological cycle is the circular movement of elements or compounds between the biota and the physical environment

SCIENCE BACKGROUND

Other terms for the ecological cycle are *biogeochemical cycle* and *nutrient cycle*.

MAIN IDEA

About 21 percent of the atmosphere is oxygen—probably of biological origin. Producers release oxygen obtained from water during photosynthesis. Other organisms use up oxygen during cellular respiration.

SCIENCE BACKGROUND

The total cycling time of oxygen between organisms and the atmosphere is estimated at 2 500 years if exchange between the atmosphere and surface water is ignored.

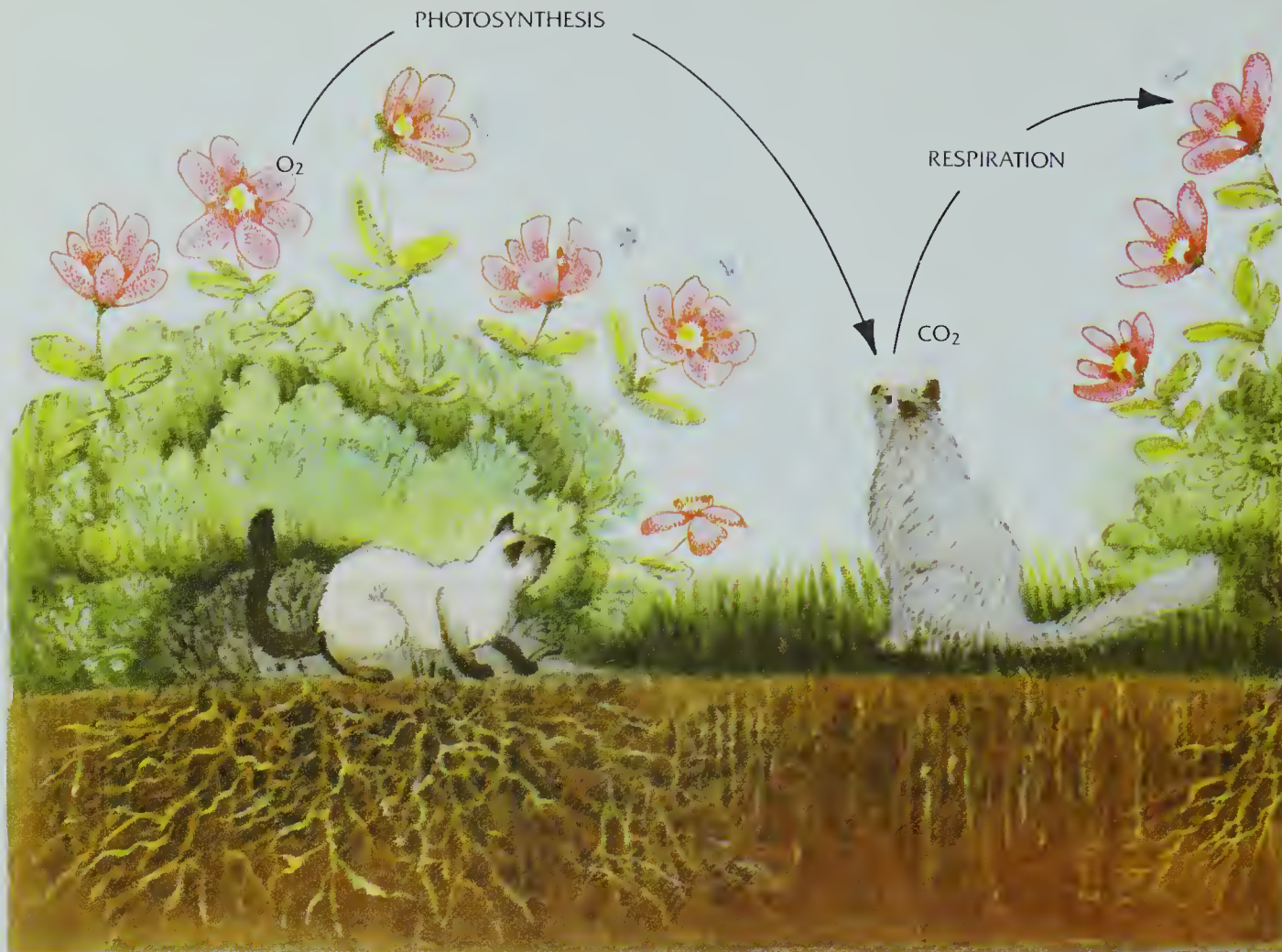


FIGURE 43-1

The oxygen cycle involves the movement of oxygen between the atmosphere and living organisms.

MAIN IDEA

Carbon is cycled mainly as carbon dioxide. This gas is a raw material for photosynthesis and a waste product of respiration. Fossil fuels are produced from dead matter that was not decomposed.

mitochondria of cells, where it serves as a hydrogen acceptor and forms water.

43-3 The carbon cycle The **carbon cycle** mainly involves the circulation of carbon dioxide (CO₂) between organisms and the atmosphere. However, the atmosphere only contains about 0.03 percent CO₂. Carbon dioxide is a raw material used in photosynthesis. It is used as a building block upon which carbohydrates and other organic molecules are formed. Some of these organic molecules are broken down by respiration in the producers that made them. Carbon dioxide is the waste product of such respiration and much of it goes back into the atmosphere.

Carbon compounds also flow from producers through the various food chains in the community. Animals use many of the carbon compounds for their own respiration, thus releasing CO₂ to the atmosphere. Decomposers also use the carbon compounds and release CO₂.

Some dead matter does not get decomposed and becomes buried in the earth. In the past, such matter developed into fossil fuels—coal, oil, and natural gas. We are now in the process of cycling that carbon back to the atmosphere. Carbon dioxide is released to the atmosphere in the processes that burn fossil fuels for energy.

43-4 The carbon dioxide question There is evidence that the amount of carbon dioxide in the atmosphere has increased in the past 100 years. Ecologists once thought this increase was coming from the increased burning of fossil fuels. Now some ecologists think that the clearing of the world's forests may be equally responsible. Forests are the greatest users of CO_2 . The increasing carbon dioxide in the atmosphere has created an important question. Ecologists call that question the **carbon dioxide question**.

Ecologists are concerned about any buildup of carbon dioxide in the atmosphere. The reason is that CO_2 absorbs infrared radiation from the earth. The CO_2 in the atmosphere serves as a kind of heat trap, which is sometimes called a **greenhouse effect**.

SCIENCE BACKGROUND

Besides CO_2 in the atmosphere, there are large inorganic pools of carbon in the earth's crust in the form of carbonate sediments.

MAIN IDEA

Evidence indicates that the atmosphere's content of carbon dioxide is increasing. This could lead to a warming trend on the earth.

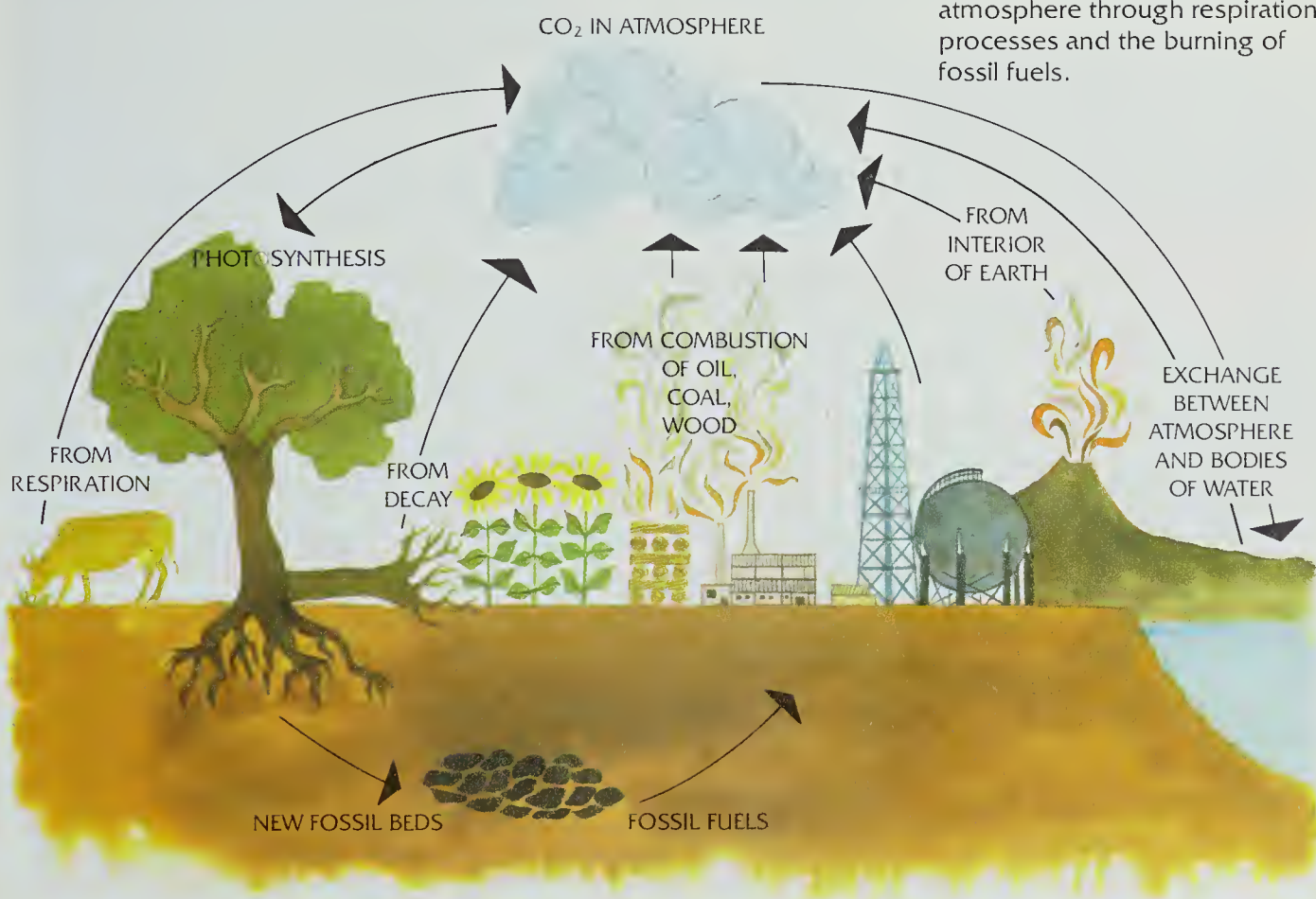


FIGURE 43-2

The carbon cycle involves mainly the use of atmospheric CO_2 by producers for photosynthesis and the returning of CO_2 to the atmosphere through respiration processes and the burning of fossil fuels.

SCIENCE BACKGROUND

For background reading, see "The Carbon Dioxide Question" by George M. Woodwell, *Scientific American*, January 1978, p. 34.

MAIN IDEA

Nitrogen from the atmosphere must be "fixed" by certain organisms before it can be used in the community. Nitrogen is returned to the atmosphere by denitrification.

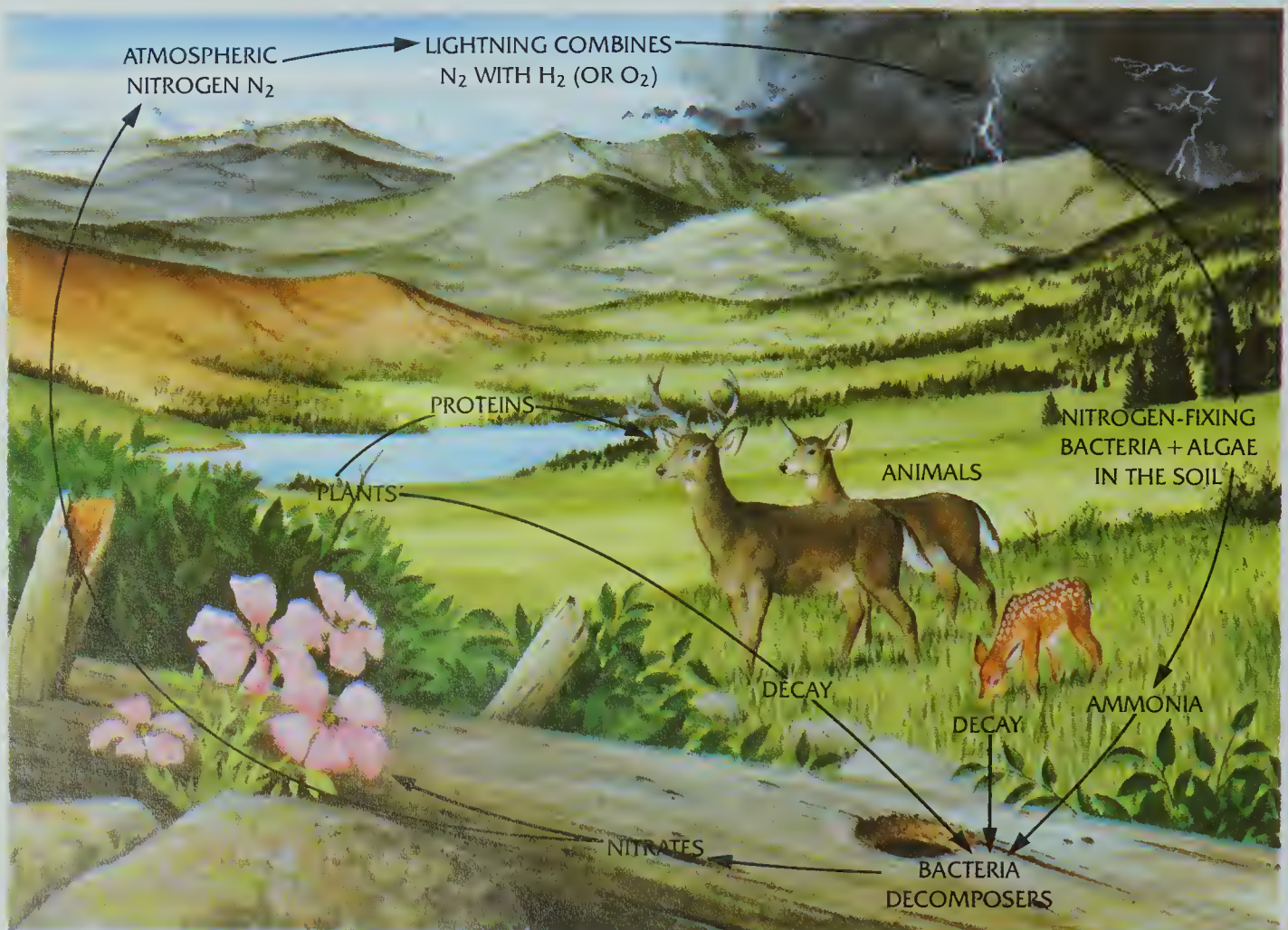
The critical question is, What might further buildup of CO_2 in the atmosphere do to the overall world climate? There is a possibility that the overall climate of the world could become warmer. It could melt the polar ice caps and cause severe flooding. It could also increase the growth of the world's deserts. This, in turn, could result in severe food shortages for an exploding human population.

It is important to emphasize that there is little evidence that such a catastrophe might happen. On the other hand, there is not enough evidence to rule out the possibility of such a warming trend. That is enough to worry ecologists and cause them to search for an answer to the carbon dioxide question.

43-5 The nitrogen cycle The **nitrogen cycle** also involves the atmosphere, but not in the same way as the carbon and oxygen cycles. Nitrogen (N_2) makes up

FIGURE 43-3

In the nitrogen cycle, certain bacteria and blue-green algae fix atmospheric nitrogen into compounds that are usable by producers.



about 79 percent of the atmosphere. However, it cannot be used by most organisms. It must first be “fixed” by a select group of organisms, which are a few species of bacteria and blue-green algae.

Nitrogen is needed in all amino acids, the building blocks of proteins. It is also needed in many other compounds. The process of fixing nitrogen requires organisms with special enzymes. These enzymes unite molecular nitrogen into **nitrates** (nī'trātz) and other compounds that organisms can use. The bacteria and blue-green algae that have these enzymes are called **nitrogen fixers**.

About 40 percent of all nitrogen fixation in nature is done by bacteria that belong to the genus *Rhizobium* (rī zō'bē əm). The *Rhizobium* bacteria perform their work as part of a mutualistic relationship with **legumes** (leg'yüms). The legumes include cultivated plants, such as peas, beans, alfalfa, and soybeans. The bacteria invade the root hairs of the legume. Eventually they reach the inside of the roots where they cause growths called **nodules** (noj'üls). The bacteria live in the nodules and carry out their activities, which include nitrogen fixation. In turn, they benefit from this mutualistic relationship by receiving nutrients and shelter inside the legume.

Nitrogen is returned to the atmosphere by the process of **denitrification** (dē nī trə fə kā'shən). Denitrification breaks down nitrogen compounds and releases molecular nitrogen. It is the opposite of nitrogen fixation. Denitrification is caused mostly by certain species of **denitrifying** (dē nī'trə fī ing) **bacteria**, which live in soil and fresh water.

43-6 Nitrogen fixation and people Agricultural scientists and ecologists are concerned that nitrogen fixation in nature cannot keep up with the nitrogen demands of cultivated plants. Originally that problem was solved with natural fertilizers that were rich in nitrogen compounds. These included cow manure and **guano** (gwä'nō). The latter is a nitrate fertilizer from Chile, made up of the body wastes of seabirds.

Later, a chemical process was developed that converted petroleum and natural gas to ammonia. Ammonia is an excellent nitrogen fertilizer. While petroleum and natural gas were cheap it seemed that the nitrogen fertilizer problem was solved. Now, however, petroleum and natural gas are declining in quantity and increasing in price. This is occurring just when the world is straining to reach maximum production of its agricultural lands. Many people tend to think of the energy crisis in relation to finding gasoline for

SCIENCE BACKGROUND

Free-living bacterial nitrogen fixers include *Azotobacter*, *Clostridium*, *Klebsiella pneumoniae* (also causes human pneumonia), and *Rhodospirillum rubrum* (a photosynthetic bacterium common on the surface of polluted ponds). A symbiotic bacterium, *Citrobacter freundii*, lives in the gut of termites and fixes nitrogen, which is deficient in wood. *Nostoc* and *Anabaena* are the two nitrogen-fixing genera of blue-green algae.

The main enzyme possessed by the nitrogen fixers is *nitrogenase*, and the process requires a large quantity of ATP for energy.

MAIN IDEA

Nitrogen fertilizers must be manufactured to keep pace with the food needs of humans. This is becoming more expensive as the cost of energy increases.

SCIENCE BACKGROUND

The commercial process of making ammonia from petroleum and natural gas is the *Haber-Bosch process*.

The nodules on the roots of this bean plant contain bacteria capable of fixing atmospheric nitrogen into nitrates.

SCIENCE BACKGROUND

The problem with culturing free-living bacteria, such as *Azotobacter*, in ponds is that they tend to decrease their activities in the presence of nitrogen compounds. However, a mutant strain has been discovered that continues to fix nitrogen and excrete ammonia in the presence of nitrogen compounds. Such a bacterium would be ideal in ponds with blue-green algae.



their automobiles. But the energy problem is broader than that. The shortage and increasing costs of energy will have a direct effect upon the amount of food that can be produced for the people of the world.

MAIN IDEA

Much research is aimed at producing fixed nitrogen compounds by natural methods.

MAIN IDEA

The water cycle, powered by the sun, cycles water in a continuous purification and redistribution process. Without the water cycle, all water on earth would become irrevocably polluted and unfit for consumption by most living things.

43-7 Nitrogen fixation research Research is now underway to find ways to turn the process of nitrogen fixation back to nature. This research is proceeding in several directions. One possible solution is to grow nitrogen-fixing bacteria and blue-green algae in "fertilizer ponds." The blue-green algae could grow on the surface and fix nitrogen. The bacteria could grow at the bottom of the ponds, live on the dead algae, and fix nitrogen.

Another type of research concerns the development of new strains of nitrogen-fixing bacteria. It would be ideal to develop strains that would grow on the roots of cultivated plants like wheat, corn, and rice. With this research there is the possibility of genetic engineering. For example, researchers have already transferred the genes for making nitrogen-fixation enzymes from one species of bacteria to another. The bacteria that received the genes can now fix nitrogen. Unfortunately the bacteria that received the genes are not the type to grow on the roots of cultivated plants.

43-8 The Water Cycle Life on earth is based upon the existence and the use of water. Organisms consist to a large degree of water and their life processes require it.



Agricultural practices may deplete the soil of nitrogen compounds. It then becomes necessary to add fertilizers if crops are to be grown.

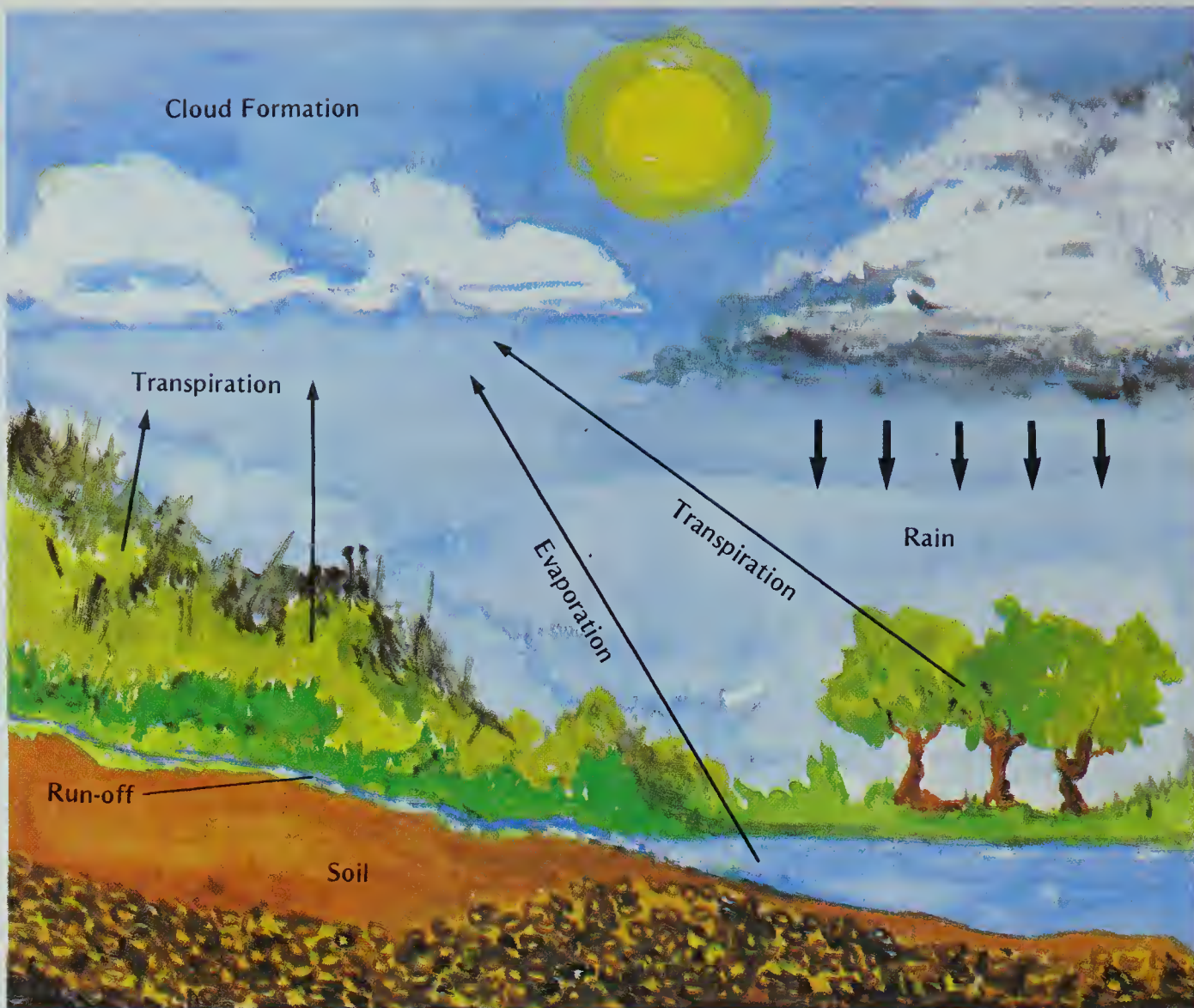
SCIENCE TERMS

ecological cycle
oxygen cycle
carbon cycle
carbon dioxide question
greenhouse effect
nitrogen cycle
nitrates
nitrogen fixers
legumes
nodules
denitrification
denitrifying bacteria
guano
water cycle
evaporation
precipitation
transpiration
acid rain

Human activities change much of the clean natural water into sewage and polluted industrial effluents. It is largely because of the naturally occurring purification process during the movement of water through the water cycle that sufficient amounts of potable water remain for consumption by living organisms.

Besides cleansing, the redistribution of water across the globe is a main function of the water cycle. Water contained in the ocean reservoirs and in lakes and rivers is constantly changing from its liquid state to vapour through the radiant energy of the sun. This process is known as **evaporation**. Evaporation occurs when water surfaces meet the atmosphere, as over all bodies of water, above moist soil, and on the surface area of most animals and plants. The evaporation of water from plants is known as **transpiration**.

Water vapour moves upwards into the atmosphere where it cools and condenses to form clouds, given the right conditions. The movement of water vapour and clouds is responsible for the redistribution of water. As conditions change, clouds return their water content to the earth's surface in the form of rain or in frozen form. Some of this **precipitation** may evaporate before it reaches the ground; a large volume will run off and enter bodies of water or return to the atmosphere through transpiration from plants. Sooner or later, most water will re-enter the water cycle and start the process over again.



ANSWERS TO CHECK YOUR FACTS

1. See section 43-1.
2. Water.
3. Carbon dioxide is the product of respiration. For respiration to be possible, oxygen gas must be present.
4. If the level of CO_2 in the atmosphere continues to increase, it could affect world climate.

ANSWERS TO REVIEW QUESTIONS

1. Plants cannot use free nitrogen gas.
2. Nitrogen in the air is fixed into usable nitrates by *Rhizobium* bacteria in the roots and

FIGURE 43-4

The water cycle involves the cleansing of water and its distribution and redistribution across the earth.

In recent years, a process that affects the water cycle has begun to occur more frequently as a result of human activity. Known as **acid rain**, it endangers natural habitats on a large scale.

43-9 Acid Rain Acid rain is believed to form when rain falls through air masses near industrial areas. This air contains pollutants such as sulphur dioxide and nitrogen oxides that originate mostly from coal-burning industrial concerns and large chemical factories. The high acidity of the precipitation kills animal life in lakes and rivers. This is a serious environmental problem as within a couple of decades, thousands of Canadian lakes could be severely affected by acid rain.

CHECK YOUR FACTS

1. What is the path of materials during the ecological cycle?
2. What is a producer's primary source of oxygen that is used in photosynthesis?
3. How does the O_2 cycle make the CO_2 cycle possible?
4. What is the CO_2 question?

SUMMARY

The circular movement of elements or compounds between the biota and the physical environment is called an ecological cycle. Material may be cycled during the life of an organism or following its death. Oxygen, carbon, and nitrogen are cycled mostly from the earth and organisms. Ecologists think that the oxygen in the atmosphere is of biological origin. Oxygen is released during photosynthesis and consumed during respiration. Carbon is cycled primarily as carbon dioxide.

REVIEW QUESTIONS

1. Why are nitrogen fixers necessary to make nitrogen available to the living world?
2. Describe what happens in the nitrogen cycle?
3. Is denitrification part of the grazing food chain or the detritus food chain?
4. How is the nitrogen cycle tied to the energy problem of the world?
5. How might genetic engineering be able to help in the nitrogen-fixing problem?
6. Identify the force that drives the water cycle and explain the various stages through which the water cycle carries out its functions.
7. What are the two main functions of the water cycle?
8. Why is the water cycle necessary to the survival of the biotic environment?
9. What is acid rain and how does it threaten the biotic environment?
10. What areas in Canada are most seriously affected by acid rain? Why?

ANALYSIS AND APPLICATION

1. A common farm practice is to alternate the crops grown in a field. Why would a sugar beet farmer consider growing a crop of beans or peas in the beet field every few years?
2. How are ecological cycles an example of interaction in an ecosystem?

root hairs of legumes. The nitrates are released to the soil and absorbed by producers. Nitrogen is freed again from the biotic environment by the denitrifying bacteria.

3. The detritus chain.
4. Ammonia is produced from fossil fuels to form artificial fertilizers. Fossil fuels are in short supply and are expensive. Food energy is made available by using up some of our fossil fuels to grow food.
5. Attempts are being made to develop bacteria strains that will grow on the roots of cultivated crops.
6. The sun. Through evaporation and transpiration, water vapour enters the atmosphere, condenses into clouds, and is carried around the globe. Clouds release the vapour as rain and the cycle is repeated.
7. Purification of water and its global distribution.
8. Unpolluted water is necessary for life on this planet. Without it, life on earth will cease to exist.
9. Sulphur and nitrogen oxides from industrial exhaust systems are carried up in the atmosphere, transformed in clouds to sulphuric and nitric acid, and fall to earth as acid rain.
10. Eastern Canada, Ontario in particular. Areas in western Canada and the eastern USA are also vulnerable. Because of heavy industrial development and resulting air pollution.

ANSWERS TO ANALYSIS AND APPLICATION

1. Legumes like beans and peas replenish the soil with nitrates through *Rhizobium* bacteria associated with their roots.
2. Raw materials from the abiotic environment are made part of the biotic world by producers and are finally returned to the abiotic world by decomposers.

44 *Ecological*



OBJECTIVES

- To review the concept of the ecological niche
- To understand the concept that any available niche in nature will eventually be filled by some population
- To explain the competitive exclusion principle
- To apply an understanding of how species compete for available niches
- To understand that succession involves a series of changes that eventually will lead to the formation of a climax community
- To understand that succession is predictable
- To describe primary succession and where it occurs
- To describe secondary succession and where it occurs

Succession

Ecological Succession

44-1 The available niche The ecological niche, or niche, is the total role of an organism or population in a community. The niche includes the habitat. The niche also includes the way an organism or population “earns its living.” By earning a living we mean the way an organism finds its food and manages to survive and leave offspring.

There is an expression that “nature abhors (dislikes) a vacuum.” That expression can be modified to express an important concept of ecology. *Any available niche in nature will eventually be filled by some population.* What the preceding concept means is this. If there is a way that a population can “earn a living” in a community, sooner or later some population will do so. This does not mean that a niche has to be vacant. It usually means that a population takes over a niche that is occupied by a less qualified competitor.

44-2 The competitive exclusion principle What if a niche is occupied by a population? Could it be shared by another population, or must it be taken over? Ecologists have found it generally true that no two populations can share exactly the same niche. Their research indicates that if two populations have to share the same niche, one always loses out. This concept is called the **competitive exclusion principle**.

Often two or more populations appear to share the same niche. For example, one field study attempted to explain how four different species of honeybees could gather nec-

MAIN IDEA

Any available niche in nature will eventually be filled by some population. This usually means that a population takes over a niche that was occupied by a less-qualified competitor.

SCIENCE BACKGROUND

The concept that every available niche in nature will eventually be filled by some population will be discussed again in Chapter 48 in relation to the ecological impact of pesticides, antibiotics, and monoculture.

MAIN IDEA

Generally no two populations can share the same niche indefinitely. Even minute differences are sufficient to provide populations with their own niche.

MAIN IDEA

Ecological succession is the sequence of changes that occurs in communities. In a mature community the final occupants of the available niches have eliminated all competition, a condition called climax.

SCIENCE BACKGROUND

The competitive exclusion principle is also called *Gause's principle* after the Russian biologist who first confirmed the principle experimentally. The work was done in the laboratory, and the basis was a mixed culture of *Paramecium caudatum* and *Paramecium aurelia*. Another well-known laboratory experiment involves two species of *Tribolium*, the flour beetle. One species of beetle always wins and the other always loses, but the "climate" in the microecosystem—whether cool-dry or warm-humid—determines which species loses and which one wins. It should be emphasized that much of the field evidence for the competitive exclusion principle is tentative or circumstantial, and the concept should not be considered firm ecological dogma.

In a mature hardwood community the dominant, or climax, vegetation may consist largely of beech trees and oak trees.

tar and pollen from the same area. The study showed that each species had a different tongue length. Each species fed mostly on different flowers and at slightly different times of the year, avoiding direct competition.

Another study was done on two species of cormorants. Cormorants are large birds that swim on water and dive for fish and other animals. Both species appeared to be feeding in the same manner. But it was discovered that one species fed on animals near the bottom. The other fed on fish and other animals at midlevels, so that the two were not in competition.

44-3 Succession in the community Many communities undergo changes over a period of time. The number and size of populations change. New populations enter the communities and others disappear.





In a mature softwood forest community the climax vegetation consists mainly of various types of pines and juniper trees.

The sequence of changes that occurs in communities is called **ecological succession** (sək sesh'ən), or succession. Succession occurs as new populations occupy available niches. Usually there is more than one population trying to succeed in any one niche. This results in competition, and the best competitors end up as the final occupants of the available niches.

Each community, if left alone, will develop into a mature community. At this stage the final occupants of the available niches have eliminated all competition, and the community is in climax. It is common practice to label the dominant types of vegetation in the mature community as climax vegetation. An example is a mature hardwood forest community where the climax vegetation is beech and oak trees. Another example is a mature softwood forest community where pine and juniper trees are the climax vegetation.

44-4 Characteristics of succession One characteristic of succession is that it is predictable. A known sequence of dominant plants populates a prairie region devastated by fire or drought. Finally the area shows the familiar groups we find in the stable mature prairie community. Along the lengthening rock channel following the toe of a retreating glacier we can find the story of succession written. It is the same story we think was played out when the original montane forest came into being.

SCIENCE BACKGROUND

The sequence of communities that replace each other in a given area is called the *sere*, and each individual community is called a *seral stage* or *developmental stage*.

MAIN IDEA

Succession is predictable. Succession results from the way communities change their physical environment.

A second characteristic of succession is that it results from the way communities change their physical environment. For example, the first plants to invade a barren area, called **pioneer plants**, are usually those that need direct sunlight. But as they grow and shade the ground, the physical environment for the seeds of other plants change. Now there is a new niche for plants that can grow in shaded areas. The seeds of shade-tolerant plants now grow and develop in this new niche. By the next growing season, the pioneer plants are no longer present because their offspring cannot develop in the shade. There is a succession from one kind of plant to another. This succession resulted from a change in the physical environment caused by the pioneer plants.

MAIN IDEA

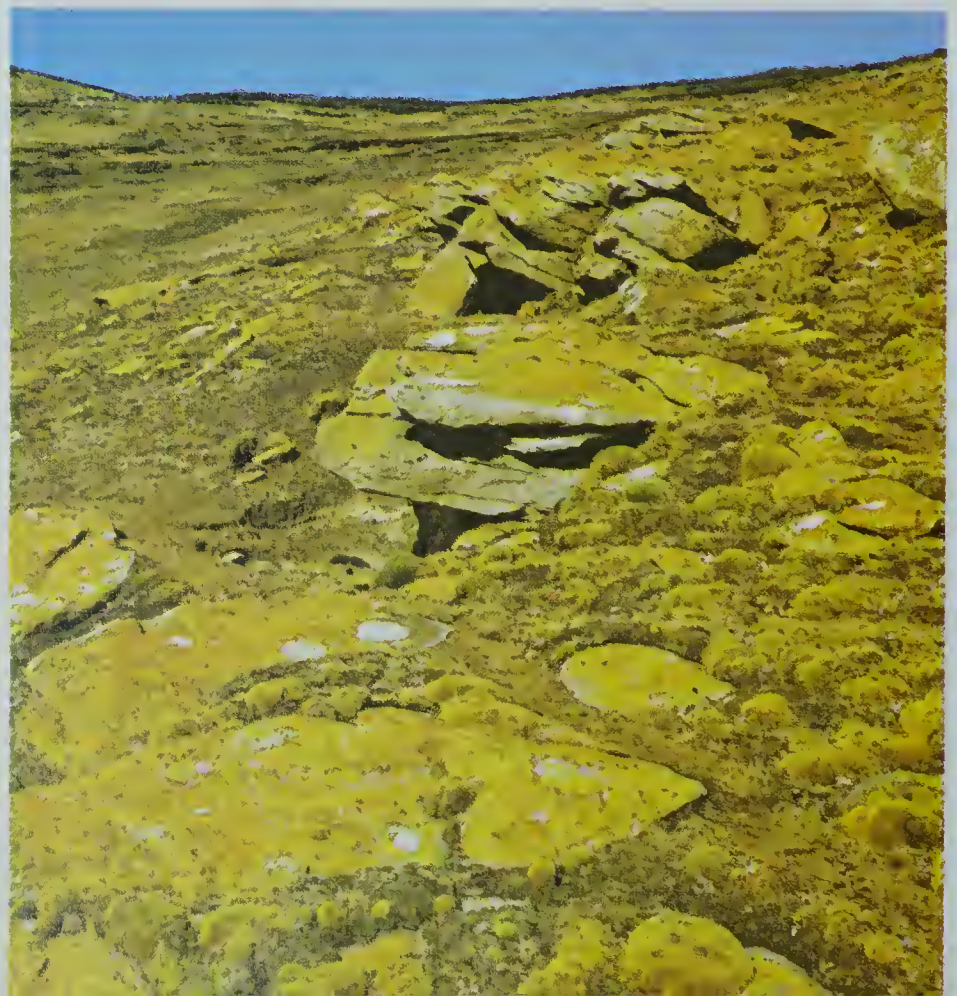
Primary succession occurs in areas where no plants have lived before. Pioneer plants must create detritus and soil before other plants can succeed them.

SCIENCE BACKGROUND

Recent studies of succession in forest environments indicate that two types of trees are involved in the competition. One type of tree, called a *multi-layered tree*, has leaves distributed throughout its total branch volume. The other type is the *monolayered tree*, which has its leaves in a single layer, forming a kind of shell over the perimeter of the tree. At high light intensities, the multi-layered tree is competitive because sunlight can penetrate to the inner leaves. These include such trees as the gray birch, bigtooth aspen, white pine, and sassafras. Such trees are the pioneers. However, the multilayered trees are at a disadvantage as the monolayered trees grow and shade them. Thus trees such as the sugar maple, the beech, and the hemlock end up in the climax community.

44–5 Primary succession Ecologists classify succession into two types. The first type, called **primary succession**, occurs in areas where no plants have lived before. Such areas include sand dunes, lava flows, or bare rock that has been exposed by a retreating glacier. On sand dunes the pioneer plants are usually grasses and other plants with root systems that hold the sand in place. Such

The first pioneers on rocky areas are often lichens.



SCIENCE BACKGROUND

Primary succession usually occurs slowly, but it can occur rapidly. For example, after the Mexican volcano Parícutin ceased erupting in 1952, all vegetation was destroyed in an area covering many thousands of acres. Within three years lichens, algae, and mosses were growing on the lava; four years later ferns were growing; and within five years flowering plants were growing on the rim of the crater.

MAIN IDEA

Secondary succession occurs after a natural community has been disturbed. Our knowledge of succession patterns enables us to predict the organisms that will appear in each stage of succession and the time required for each stage.

An abandoned farm ripe for succession

plants also provide detritus, which, in turn, provides niches for microorganisms and small animals. The detritus helps hold moisture and serves as a seed bed for the seedlings of small trees. As the trees develop they provide niches for birds, more insects, and other animals.

Primary succession on bare rock is a much slower process. The first pioneers normally are lichens, which can tolerate strong sunlight and the dry habitat on bare rocks. The lichens break down the rock, the first stage of soil production. With a minimum amount of soil, other plants can become established. If there is enough moisture, plants like mosses, liverworts, and ferns may fill the niches. In drier regions, plants adapted to living with little moisture will follow the lichens.

44-6 Secondary succession The second type of succession, called **secondary succession**, occurs after a natural community has been disturbed. Such a disturbance could be a natural disaster such as a fire, avalanche, or earthquake. Secondary succession often results from human activities. Logging, mining, and farming, are the most common disturbances that are followed by secondary succession. Earlier in this century, a severe ten year drought settled on North America. It changed both natural



SCIENCE BACKGROUND

Any abandoned garden is a good place to study secondary succession. Some students will have wrestled with the typical pioneer plants if they have been required to pull or hoe weeds from an existing garden. For rural students this is a good way to show how tough and competitive such plants can be when good niches are available. Few gardeners can keep out all the pioneer plants, even when they work hard at the task.



This photo of shifting sands in northwestern Saskatchewan is an example of duning as it occurred during the Dust Bowl era. Pioneer grasses are beginning to take hold.

and developed plant communities. Plants whose root systems held the topsoil together died from lack of water. Winds lifted precious soil components from the land and left them in barren dunes. The midwest earned the name of **Dust Bowl**. With the return of the more familiar rainfall patterns, the plant communities began to rebuild.

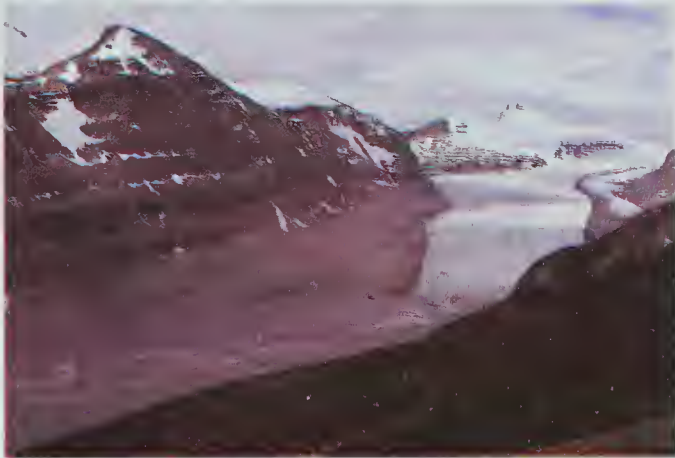
Grasses with shallow rooting systems grew from seeds scattered by the deadly winds. Slowly the vital nutrients were restored to the soil. The mat of roots and drying plant substances held the water. The wind could no longer reach the surface areas with excessive force. Deeper-rooted grasses and shrubs could now compete with the pioneer species. Where there was more abundant water supply, softwood saplings might invade the area. By shading the ground they were able to replace pioneer species that are not shade tolerant. The numbers and kinds of plants now approached the climax population.

The pattern found at this stage is very similar to the one found before the disaster. The rebuilding of an earlier pattern of vegetation is an example of secondary succession.

The spiny ridge of mountains we call the Rockies was thrust upward from the ocean floor. Any plants which grew on this emerging land were scoured away by a moving cap of ice. As the glaciers melted they left bare rock without soil for roots to penetrate. In many places on the continent this melting continues. As a glacier slowly melts, it exposes a steep-walled valley littered with rock fragments. In a canyon length of only a few kilometres we can see the progression from a barren wasteland to a mature forest. A niche is created which can be filled by lichens clinging to the rocky surfaces. Mineral substances are dissolved and rock fragments are released. Soil begins to form along the stream of icy meltwater. Now mosses and tiny alpine plants can become established. With this new community of plants, birds and other animals take up homes, bringing seeds from other areas. Since this valley is surrounded by a balanced and relatively stable ecosystem, it matures rapidly. At lower levels along the stream it blends

SCIENCE TERMS

competitive exclusion principle
ecological succession
pioneer plants
primary succession
secondary succession



Glaciers in northern Saskatchewan and Banff National Park, Alberta. When glaciers melt, the exposed and barren rockstrewn valleys are first invaded by those most hardy of pioneers: lichens.



Eventually, mosses and other plants take a foothold in the once barren valley. Years after the melting of the glacier, a completely new community has matured.

perfectly into the older forest. Eventually, beaver will find sufficient food near the water from willows and poplars and begin to dam the stream. Now the pines and poplars which have their roots in the pond water will die, giving way to the spruce that started in the shady dampness of the forest floor.



Infrared photograph of a mountain ridge in British Columbia. These limestone mountains in southeastern British Columbia were carved out by a glacier thousands of years ago. Rocks appear as grey-white, the lake is blue-black, and green plants are seen as pink or red areas. The pink circular area below the lake shows grasses and willow trees. On the grey-white slopes, pioneer plants reflect a light pink colour. In the upper right-hand side, the red area marks a stand of poplar trees.

CHECK YOUR FACTS

1. What is an available niche?
2. What is the competitive exclusion principle?
3. What is a niche?
4. What is ecological succession?

SUMMARY

An important concept in ecology is that any available niche in nature will eventually be filled by some population. Sometimes an available niche will be a vacant niche. Usually, however, the available niche is occupied by a less qualified competitor and is taken over by a more qualified population. The competitive exclusion principle states that two populations cannot share the same exact niche indefinitely. However, even the tiniest differences are often enough to allow populations to avoid direct competition and thus to live together in similar niches. The changes that occur in communities are called ecological succession.

REVIEW QUESTIONS

1. What are the interrelationships upon which succession depends?
2. What is a mature community?
3. What is a climax community?
4. What are the major characteristics of succession?
5. What is a pioneer plant?
6. What is primary succession?
7. What are the typical pioneer plants in sand dune succession?
8. Why is succession on bare rock slower than succession on sand dunes?
9. How is secondary succession different from primary succession?

ANALYSIS AND APPLICATION

1. Why is succession predictable?
2. In recent years the agencies in charge of our large forests and range lands have changed their fire-fighting policy. They no longer try to extinguish every natural fire (i.e., a fire caused by lightning) that occurs if it does not endanger lives, private property, or large populations of organisms. What reasons might these agencies have for this decision?

ANSWERS TO CHECK YOUR FACTS

1. A niche that is either unfilled in a community or is imperfectly filled.
2. The principle that only one population can occupy a niche at one time.
3. The total role of the organism in the community.
4. The sequence of changes in communities.

ANSWERS TO REVIEW QUESTIONS

1. Competition for niche occupancy. Changes in the abiotic environment may change the nature of the habitat sufficiently so that new populations can more successfully compete.
2. Any combination of populations that can retain occupancy of their niches.
3. The last community that fills a niche.
4. It is predictable, and it occurs because of changes in the abiotic environment that result from the activities of the biota living there.
5. A producer that is the first to invade a barren area.
6. The succession that occurs in an area where no plants have lived before.
7. Grasses and herbs.
8. Pioneers on bare rock must build soil.
9. Secondary succession occurs where some stage of succession has been interrupted and succession must start again.

ANSWERS TO ANALYSIS AND APPLICATION

1. The abiotic aspects of ecosystems determine which biota can occupy them successfully.
2. Fire is a natural agent for interrupting and retarding succession in an area.

Investigation 61 from *Laboratory Investigations in Biology* can be done with this chapter.

45 *The Freshwater*



OBJECTIVES

- To list the names and general characteristics of the two types of freshwater habitats
- To understand the five limiting factors that determine whether an organism or a population can live in a freshwater habitat
- To explain the ecological classification of freshwater organisms
- To know the three habitat zones in the lentic community and a type of organism that lives in each
- To know the two habitat zones in the lotic community and the kinds of organisms that live in each

Habitat

The Freshwater Habitat

45-1 Types of freshwater habitats A **freshwater habitat** is an aquatic habitat that is not a sea or an ocean. Freshwater habitats are divided into two types. One is the standing-water, or **lentic** (len'tik), habitat. Lentic habitats include lakes, ponds, swamps, bogs, and temporary drainage water, such as the common "mudhole." The main characteristic of a lentic habitat is the lack of flowing water, or current, through the body of water.

The second type of freshwater habitat is the running-water, or **lotic** (lō'tik), habitat. Lotic habitats have a current. They include rivers, streams, and springs.

45-2 Limiting factors In any habitat there are **limiting factors** that determine whether an organism or population can live in the habitat. In freshwater habitats there are five main limiting factors.

One of these is temperature. Most bodies of fresh water have a temperature range that is narrow, compared to land habitats. The organisms that live in the water are adapted to this narrow range of temperatures. Drastic changes, such as the dumping of hot water into a body of water, can destroy many forms of freshwater life. **Thermal** (thēr'məl) **pollution** affects freshwater life by increasing the temperature of the water.

A second limiting factor is the transparency of the water. Transparency is a measure of how far light penetrates. The amount of light is a limiting factor on photosynthetic organisms, the producers in the freshwater habitat.

MAIN IDEA

A freshwater habitat is any aquatic habitat that is not a sea or an ocean. Lentic refers to standing water; lotic, to running water.

MAIN IDEA

The limiting factors in freshwater habitats are temperature, water transparency, current, dissolved oxygen, and dissolved compounds.

SCIENCE BACKGROUND

It is strongly recommended that the students, where possible, make a complete inventory of the freshwater habitats within some radius of the school. These can then be classified into lentic and lotic habitats.

SCIENCE TERMS

freshwater habitat
lentic
lotic
thermal pollution
neuston
periphyton
benthos
plankton
phytoplankton
zooplankton
nekton
littoral zone
limnetic zone
profundal zone
rapids zone
pool zone



Brine shrimp are free-swimming crustaceans and part of the zooplankton of many freshwater habitats. They feed largely on algae.

Current is the third limiting factor. Current creates pressure on everything in the water. It is a limiting factor on all populations that do not have special adaptations for withstanding the pressure.

The fourth limiting factor is dissolved oxygen. Populations vary in the amount of oxygen that they need in the water. Temperature and current affect the dissolved oxygen content. For example, cold water will hold more dissolved oxygen in solution than warm water. Current can be related to dissolved oxygen content because moving water usually dissolves more oxygen than standing water. A strong current that rumbles over rocks and forms “white water” will cause more oxygen to be dissolved.

The fifth limiting factor is dissolved compounds. For example, fresh water varies in its contents of dissolved nitrates, phosphates, and chlorides. Some of the dissolved compounds are essential nutrients that all organisms need to some degree. Others, like the salt in most salt lakes, have a negative influence. The only animal adapted for living in that water is the brine shrimp.

45-3 Ecological classification of freshwater organisms Ecologists classify organisms in fresh water according to their habitat and their patterns of life. Each population is placed in one of five categories. Organisms that rest or swim on the surface are the **neuston** (nūs'tən). Those that are attached to rooted plants or objects sticking up from the bottom are the **periphyton** (pə rif'ə ton). Those that live on the bottom or in the bottom sediments are the **benthos** (ben'thos).

This leaves two more categories for the populations that live suspended in the water itself. One category, the **plankton** (plangk'tən), includes all the organisms that are suspended in the water but swim poorly or not at all. Much of the plankton is made up of small organisms, and many are microscopic. The plankton is further classified into two types. The **phytoplankton** (fī tō plangk'tən), or plantlike plankton, is made up of producers, mostly algae. The phytoplankton carries on photosynthesis and is at the beginning of grazing food chains in fresh water. The **zooplankton** (zō ə plangk'tən), or animallike plankton, is made up of consumers, many of which feed on the phytoplankton. Much of the zooplankton is made up of small crustaceans, such as *Cyclops* and *Daphnia*.

The final category is the **nekton** (nek'ton), which is made up of animals that are good swimmers. These include fishes, amphibians, turtles, and a variety of insects.

Diatoms form a large part of the phytoplankton community in both marine and freshwater habitats.



The water flea, *Daphnia*, lives year round in freshwater lakes and ponds. It feeds on bacteria and algae and is itself food for certain fish.

MAIN IDEA

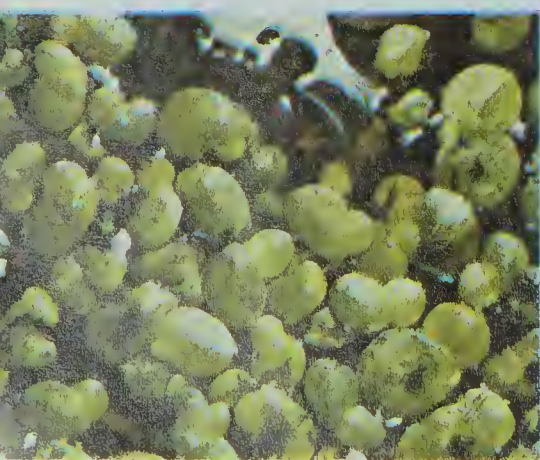
Freshwater organisms are classified as neuston, periphyton, benthos, plankton, or nekton. Plankton are divided into phytoplankton and zooplankton.





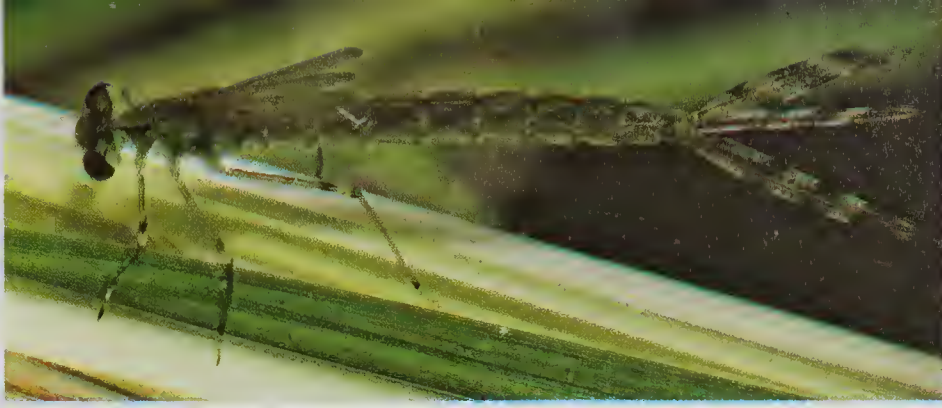
FIGURE 45-1 A lentic habitat, such as a pond, will have a littoral zone, a limnetic zone, and perhaps a profundal zone.

The larvae of damselflies can be seen among the duckweed in the photograph below.



45-4 The lentic community Lentic communities have three zones, each with their own characteristic populations. The zones are based upon the degree of light penetration. The **littoral** (lit'ər əl) **zone** is the shallow-water region where light penetrates all the way to the bottom. The **limnetic** (lim net'ik) **zone** is an open-water zone. It extends downward to a depth where there is enough light for good photosynthetic activity. The third zone, the **profundal** (prə fun'dəl) **zone**, is the deep region. In the profundal zone there is not enough light for a significant amount of photosynthesis to occur. In shallow ponds, swamps, or bogs there is usually no profundal zone.

The littoral zone is the most productive part of lentic communities. Often there are rooted plants like cattails, with numerous animals attached or swimming around them. The neuston typically includes duckweed, water striders, and small black whirligig beetles. The latter whirl



The damselfly nymph is an inhabitant of the littoral zone of lentic communities. It feeds on aquatic organisms such as mosquito larvae.

around in circles rapidly when they are disturbed. The littoral zone is also rich in plankton and in certain kinds of fishes, such as sunfishes and bass.

The limnetic zone consists mostly of plankton and nekton populations. The plankton in this region tends to be smaller than in the littoral zone. The limnetic nekton consists of almost all fishes; however, an occasional turtle may swim through the zone.

The populations living in the profundal zone must depend upon food that originates in the littoral or limnetic zones. The major organisms here are bacteria and fungi, which live in the mud. Various kinds of worms, small clams, and some kinds of insect larvae are also found here. Animals that survive in the profundal zone have to be adapted for living on small amounts of oxygen. Many of the bacteria of the region are anaerobic.



The dragonfly nymph is also an inhabitant of the littoral zone and like the damselfly nymph often feeds on insect larvae.

SCIENCE BACKGROUND

Each student should know the common name of at least one or two organisms in each category.

MAIN IDEA

Lentic communities have three zones: the littoral zone, or shallow region; the limnetic zone, or open-water region; and the profundal zone, or deep region. The littoral zone is the most productive; the profundal zone, the least productive.

The sunfish is found in the limnetic zone. Its food consists of small animals such as insects, worms, and other fish.



ANSWERS TO CHECK YOUR FACTS

1. In a lentic habitat the water is still. In a lotic habitat the water moves and has a current.
2. Temperature, water transparency, current, dissolved oxygen, and dissolved compounds.
3. The dumping of water of a different temperature into a body of water and thereby changing the average temperature of that water.

MAIN IDEA

Lotic communities have two zones: the rapids zone and the pool zone. Special adaptations are needed by organisms living in the rapids zone.

ANSWERS TO REVIEW QUESTIONS

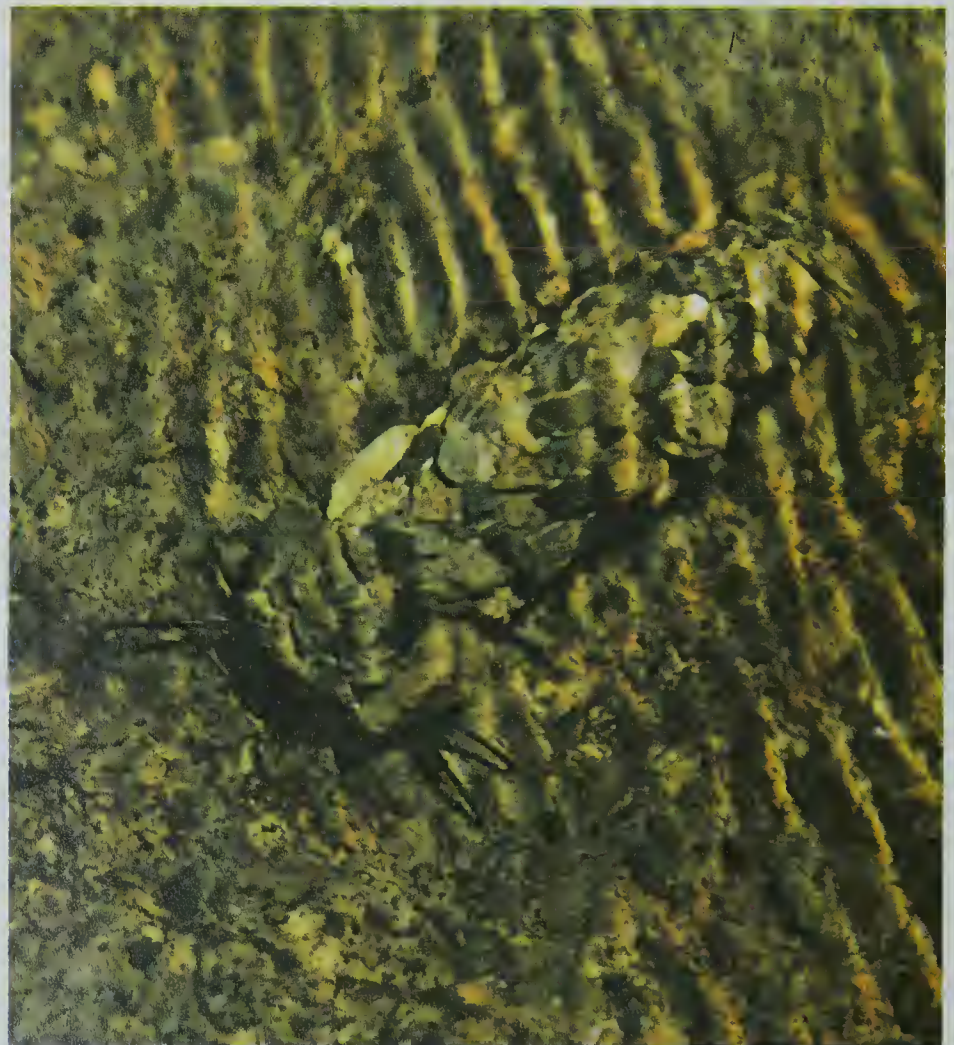
1. Freshwater organisms are generally tolerant of only a narrow temperature range; the water temperature and the current influence the required concentration of dissolved oxygen; the transparency of the water affects photosynthesis; the amount of essential dissolved materials varies; and only some organisms can survive the pressure of a current.
2. The neuston group rests and swims on the surface film; the periphyton attaches to rooted plants or objects that stick up from the bottom; and the benthos lives in the bottom sediments.
3. Plankton is made up of organisms that swim poorly or not at all. The good swimmers are the nekton, such as fishes and turtles.

45–5 The lotic community In lotic communities, which include rivers, streams, and spring habitats, there are two zones. One, the **rapids zone**, is the region where the current is strong enough to keep the bottom clear of loose material. The second zone, the **pool zone**, is the quiet water of the stream, where loose materials settle on the bottom.

Organisms living in the rapids zone have special adaptations for surviving the pressure of the moving water. Some have hooks and suckers that they use to hold themselves to a firm object. Some have flattened, streamlined bodies. Others, such as planarians and snails, secrete a sticky material that holds them in place.

Many of the organisms in the pool zone are similar to those found in the littoral zone of lentic communities. For example, it is common to find duckweed, water striders, and whirligig beetles in the neuston of a lotic pool zone.

The larvae of caddis flies may be found in both lentic and lotic communities where they are an important food source for many fish.



CHECK YOUR FACTS

1. What is the difference between a lentic and a lotic freshwater habitat?
2. What are the five limiting characteristics of a freshwater habitat that determine what organisms live there?
3. What is thermal pollution?

SUMMARY

Any aquatic habitat that is not in a sea or ocean is called a freshwater habitat. Standing-water habitats are called lentic habitats, while running-water habitats are called lotic habitats. Organisms that live on the surface are called neuston. Periphyton live attached to rooted plants. The benthos inhabit the bottom of a body of water. Nekton includes the free-swimming organisms. Plankton includes those organisms suspended in the water. Phytoplankton are producers, while zooplankton are consumers. Lentic communities have three zones: littoral, limnetic, and profundic.

REVIEW QUESTIONS

1. Why do the five limiting factors of a freshwater habitat determine which organisms live there?
2. What are the characteristics of the three groups of freshwater organisms that are not found swimming in the water itself?
3. What are the characteristics of the two groups of organisms that are free in the water?
4. What are the characteristics of the three zones of a lentic community?
5. What is a source of food in the profundal zone?
6. What are the two zones of a lotic community?
7. How are the pool zones of the lotic habitat similar to the littoral zones of lentic habitats?
8. What difference is there between the lotic pools and the lentic littoral zone?

ANALYSIS AND APPLICATION

1. Use reference books on freshwater habitats to design a lentic community with at least two organisms in each habitat. Try to pick organisms that you can find in the freshwater communities near you. Draw the organisms in the different zones and label them with their common name.

4. In the littoral zone, light for photosynthesis reaches the bottom of the lake; in larger lakes, light penetrates the limnetic zone but does not reach the deep profundal zone.
5. Consumers in the profundal zone feed on producers and consumers that migrate from the littoral and limnetic zones.
6. The rapids zone and the pool zone.
7. In both areas there is little current and ample light for photosynthesis. Similar organisms will be found in the two areas.
8. There is a constant supply of nutrients and organisms brought to the lotic pools and a constant removal of wastes. In the lentic littoral zone there is less exchange of nutrients and organisms.

ANSWERS TO ANALYSIS AND APPLICATION

1. Neuston may include water striders, whirligig beetles, springtails, and fishing spiders. On the bottom of still water the greatest diversity is found. Bacteria and fungi are the important decomposers here, but they are not obvious. Amoebas, freshwater sponges and bryozoans, mussels and clams, hydra, roundworms (nematodes), sludgeworms (*tubifex*), bloodworms (midge larvae), planarians, snails, crayfishes, and leeches are some of the benthos likely to be found. Periphyton will include the insect larvae typical of your area, hydra, snail eggs and snails, and planarians. Also, different blue-green and green algae, diatoms and desmids, protozoa, rotifers, *Daphnia*, and copepods are likely to be the periphyton or plankton. Any fishes, turtles, water snakes, or tadpoles common to your area could be chosen as nekton.

46

OBJECTIVES

- To understand that the marine habitat covers 70 percent of the earth's surface
- To explain the role of currents and upwellings in

The Marine



- climate and production
- To understand that the ecological classification of organisms is the same for both marine and freshwater organisms but that the term *pelagic* refers to all organisms in open water
- To name the three horizontal zones and the three

- vertical zones of the marine habitat
- To describe the role of phytoplankton in the energy flow through the marine communities
- To know the basic groups of organisms that are well represented in marine communities

- To appreciate that the coral reef is a unique marine ecosystem
- To understand the nature of estuaries and why they are important
- To appreciate the potential role of estuaries in helping solve the future food-growing problems of the world

Habitat

The Marine Habitat

46-1 General characteristics The **marine habitat** is the sea or ocean habitat. It is the largest habitat. Marine waters cover 70 percent of the earth's surface. The water in the marine habitat is in constant motion. These movements are caused by winds and tides. The main circulation of the marine waters is of two types. One type is the **ocean current**, which circulates water like giant rivers. Examples of major ocean currents are the Gulf Stream and the Labrador Current. The Gulf Stream carries warm water from the semitropical Caribbean region to northern Europe. The Labrador Current brings cold northern water to the east coast of Canada.

The second type of circulation is vertical. Water flows from the bottom upward. This type of circulation is called **upwelling** (up wel'ling). Upwelling is very important for the survival of marine life. Much of the marine detritus settles to the deep regions of the ocean. There is a loss of nutrients from the communities that are concentrated near the surface. The loss of nutrients would be permanent if it were not for upwelling. Upwelling causes the nutrients to be cycled back near the surface where they can be used again. The most productive parts of the ocean are regions where there is strong upwelling. These regions are generally in areas where strong winds blow.

46-2 Ecological classification of organisms The terms used to classify freshwater organisms also apply to those in the marine habitat. The poor swimmers are the

MAIN IDEA

The marine habitat is the largest habitat. Winds, tides, currents, and upwelling keep ocean water in constant motion. Upwelling circulates nutrients that have settled to the bottom.

SCIENCE BACKGROUND

The marine habitat is continuous, but there are limiting factors that effectively serve as barriers to the movement of organisms. The main factors are temperature, salinity, and depth.

Students often overlook the importance of upwelling in the marine habitat. It should be emphasized that without upwelling, much of the oceans would be nearly sterile because of the lack of critical minerals.

MAIN IDEA

The terms used to classify freshwater organisms also apply to marine organisms. *Pelagic* refers to life in open water.

plankton. The good swimmers are the nekton. The benthos live in or on the bottom. The neuston, or top dwellers, and periphyton, or attached forms, are unimportant.

Another term that is often used by marine ecologists is **pelagic** (pə laj'ik), which refers to all life in the open water. Pelagic organisms include all the plankton, nekton, and neuston.

MAIN IDEA

Three horizontal zones are the intertidal, the neritic, and the oceanic zones. Vertical zones, from top to bottom, are the euphotic, the aphotic, and the abyssal zones.

SCIENCE BACKGROUND

Neritic means "near shore."

The intertidal zone is also called the littoral zone. One reason why the oceanic zone is not an abundant producer of life is the thinness of the euphotic zone.

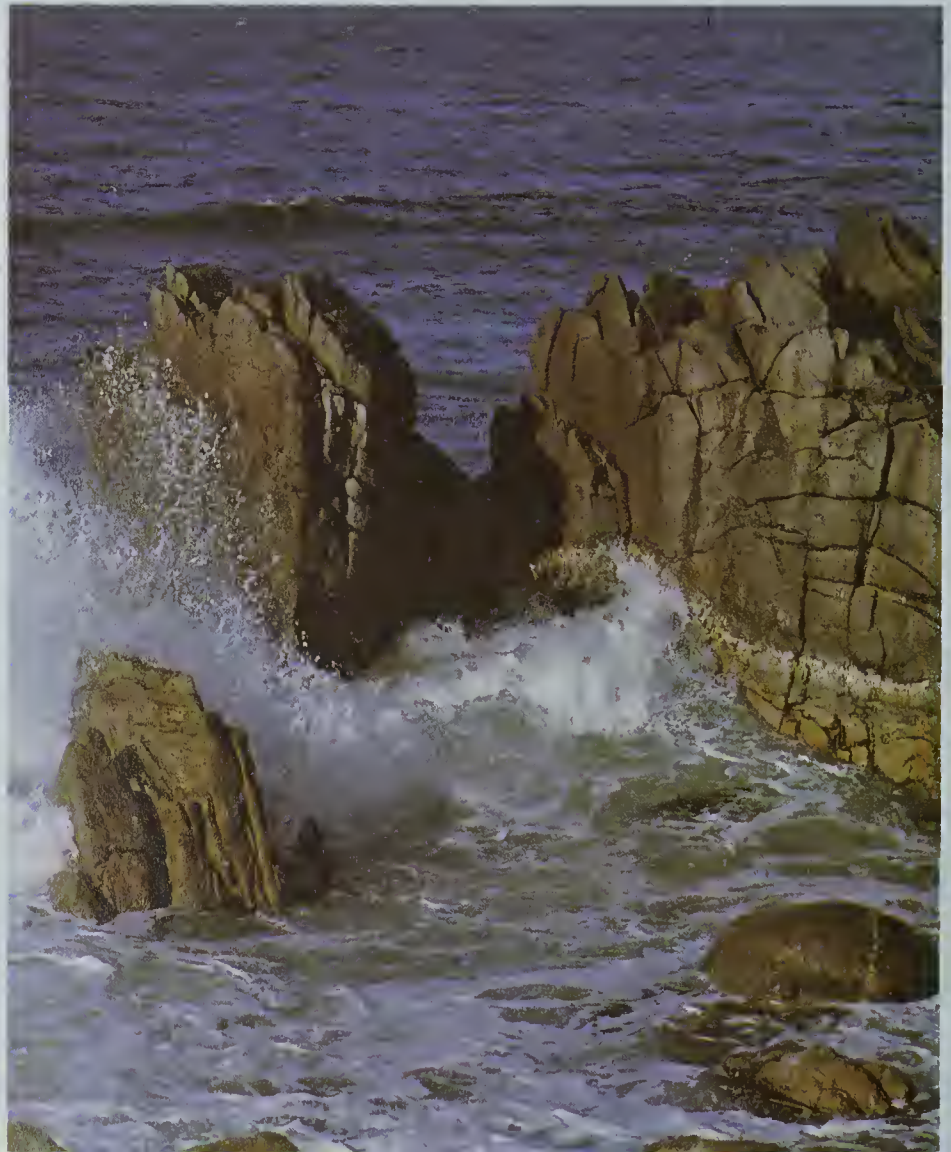
Students often think that the deep blue transparent waters of the tropics are full of life. Actually such waters are like deserts compared to the more opaque waters that are clouded by layers of phytoplankton.

The fishes of the abyssal zone have a number of adaptations for survival, including huge mouths, lanterns, and bizarre shapes that allow them to hide. Almost any book on oceanography includes pictures and descriptions of these strange animals, which students usually find interesting.

The shoreline or coast constitutes the intertidal zone of a marine habitat. Seaweed and barnacles are examples of organisms from this zone.

46–3 Zones in the marine habitat A different set of terms is used to describe the various life zones in the marine habitat. One of the zones is along the shoreline, which is sometimes covered by water and sometimes not. This is the region where the tides ebb and flow, and it is called the **intertidal** (in tər tī'dəl) **zone**.

Just beyond the shoreline the bottom slopes gradually for a distance and then drops steeply into the deep ocean. The gently sloping region is called the **continental shelf**. The water over the continental shelf forms another zone, the **neritic** (ni rit'ik) **zone**. Beyond the neritic zone the remainder of the ocean is called the **oceanic zone**.





Although the Antarctic is often thought of as being unfavorable to life, the green color of the water indicates that it is teeming with organisms.

The three zones are separated from each other on a horizontal plane. Other zones are divided on a vertical plane, from the surface to the bottom. The top zone, the **euphotic** (yü fot'ik) **zone**, is the zone that light penetrates. The euphotic zone is thin, but in some tropical waters it may extend downward for 100 to 200 m. The region below the euphotic zone, where light does not penetrate, is the **aphotic** (ā fo'tik) **zone**. The aphotic zone is many times thicker than the euphotic zone. In other words, most of the ocean habitat is completely dark. A third zone is often used to define the deepest parts of the marine habitat. This is the **abyssal** (ə bis'əl) **zone**, which ranges from 2 000 to 5 000 m below the surface.

46-4 *Energy flow in marine communities*

The seed plants are almost absent from the marine habitat. The producers that start the energy flow through the marine habitat are almost entirely the phytoplankton. The most important kinds of phytoplankton are very small. They include diatoms and green flagellates that are suspended in the top layers of the water.

SCIENCE BACKGROUND

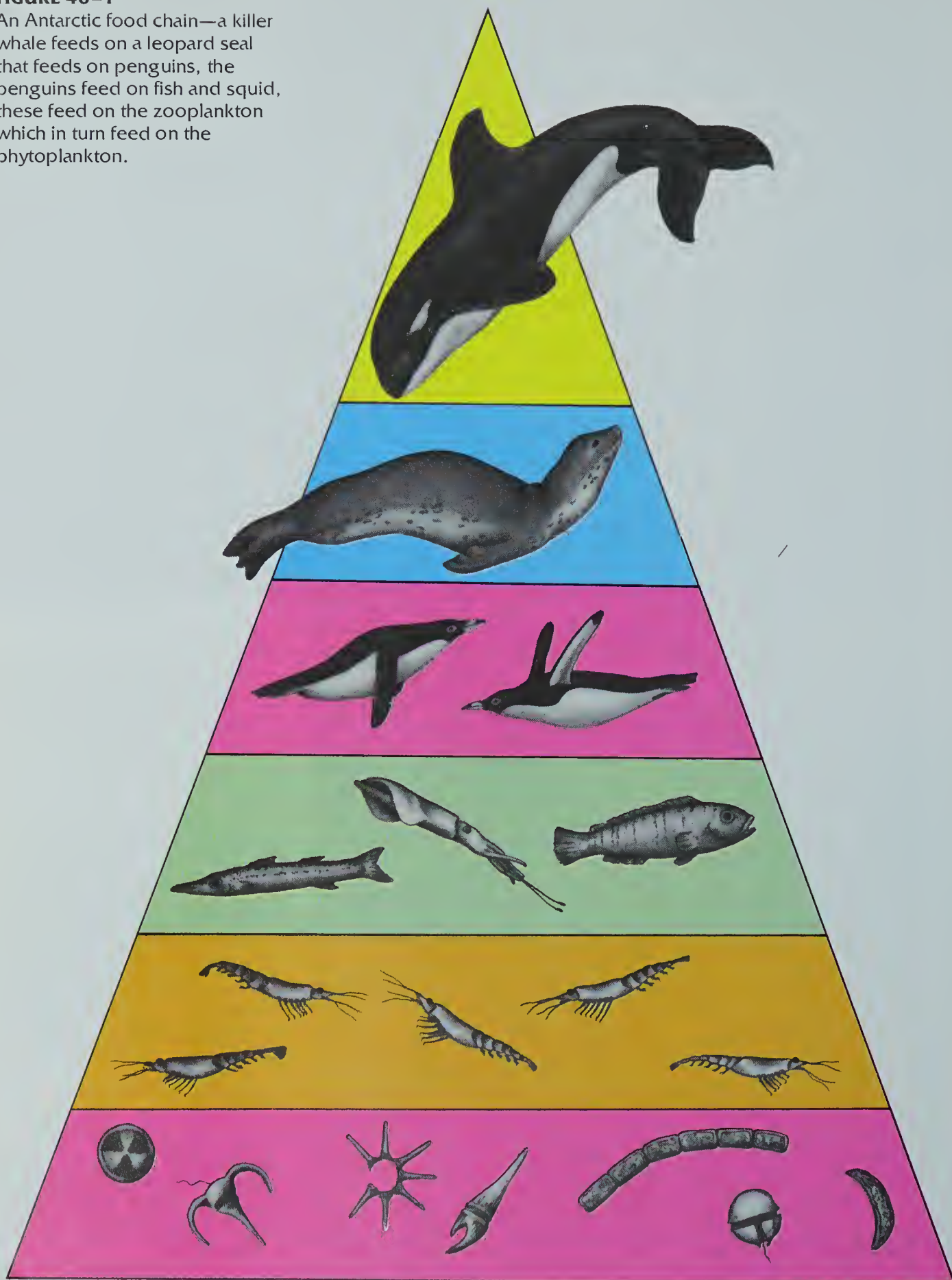
The *nannoplankton* (*nanno*, meaning "dwarf") are the most important photosynthetic organisms. These are phytoplankton that range in size from 2 to 25 μm and pass through the smallest meshes of plankton nets.

MAIN IDEA

Most producers in marine habitats are phytoplankton. Zooplankton are the main first-order consumers.

FIGURE 46-1

An Antarctic food chain—a killer whale feeds on a leopard seal that feeds on penguins, the penguins feed on fish and squid, these feed on the zooplankton which in turn feed on the phytoplankton.



The first-order consumers, or grazers, in the marine communities are the zooplankton. In turn, the zooplankton are eaten by a variety of animals including the largest animal of all, the blue whale.

46-5 Kinds of organisms in marine communities There are certain groups of organisms that are much more common in marine communities than anywhere else. These include the red and the brown algae, sponges, coelenterates, mollusks, annelids, and crustacea. The echinoderms are marine animals, and they are not found in any other type of community. The insects, which are the most abundant animals on the land, are almost completely absent from the marine habitat.

There is an interesting difference in the structure of marine communities as compared to those in fresh water. In marine communities there are many more sessile (stationary) organisms among the benthos than in fresh water. Many, like sponges and sea anemones, actually look like plants growing on the bottom.

46-6 A unique community There is one unique kind of marine community—the **coral reef**. The reef itself is a huge body of porous limestone material. It is built over many years by tiny coral animals and other organisms.

MAIN IDEA

Common marine organisms are the red and the brown algae, sponges, coelenterates, mollusks, annelids, crustacea, and echinoderms. Insects are rare. More sessile organisms occupy the benthos in marine habitats than in freshwater habitats.

MAIN IDEA

The coral reef is a complete ecosystem. It is built by coral and other organisms.

SCIENCE BACKGROUND

The crustacea are the “insects” of the sea. They make up a large part of the zooplankton.

The sessile organisms in the benthos also serve one of the same ecological roles as trees on the land. They provide a habitat for a variety of organisms.

This damselfish is a member of a coral reef community. The reef is made mostly by corals, animals belonging to phylum Coelenterata.



What is unique about the reef is that it is a complete ecosystem. The reef community has its own producers and consumers. The latter include a variety of beautifully colored fishes that dart in and out of the reef passageways.

MAIN IDEA

Estuaries are unique and productive habitats that serve as nursery grounds for many animals. Estuaries contain brackish water—a mixture of seawater and fresh water.

SCIENCE BACKGROUND

Estuary means “tide.” The five types of estuaries include (1) drowned river valleys, such as Chesapeake Bay; (2) drowned fjords, like those in Norway, British Columbia, and Alaska; (3) bar-built estuaries that form behind barrier islands and sandbars; (4) those produced by tectonic processes, such as faulting or subsidence, as in San Francisco Bay; and (5) river deltas, such as the mouth of the Mississippi.

The spotted sea trout is an example of fishes that are largely restricted to estuaries.

SCIENCE TERMS

ocean current
upwelling
pelagic
intertidal zone
continental shelf
neritic zone
oceanic zone
euphotic zone
aphotic zone
abyssal zone
coral reef
estuary
brackish water
nursery grounds
mariculture

46–7 *The estuary: another unique habitat*

An **estuary** (es'chü er ē) is a semienclosed coastal body of water. It has a connection to the sea and is fed with fresh water that drains from the land. A typical estuary is the mouth of a major river. An example is Chesapeake Bay. Other estuaries develop behind sand bars and may be called such names as *sounds* and *salt marshes*.

The water in this estuary in Georgia is brackish. Many organisms are adapted to living in this environment.





Marine farming, called mariculture, can involve the cultivation of edible seaweed (above) and various types of marine animals.

The estuary is a unique habitat because of its water. It has a mixture of fresh water and seawater, which is called **brackish** (brak'ish) **water**. The salt content of the brackish water varies, depending upon runoff and evaporation. Most species of the biota in the estuary are adapted for the habitat. Many are not found elsewhere.

Estuaries are extremely important habitats. They are more productive than freshwater or marine habitats. They trap nutrients and are shallow enough for photosynthesis to occur. Their major importance is their function as **nursery grounds** for many commercial animals and sport fish. Many fish from the ocean come to the estuaries to spawn, or lay eggs. Many commercial types of shrimp spend their larval, or young, stages in estuaries. In addition, the estuary is the main habitat for such animals as the oyster and the crab.

46-8 Estuaries and the future Marine ecologists believe that estuaries are not appreciated by enough people. In past years the estuary has been a favorite dumping ground for many kinds of wastes. This has created severe pollution in some estuaries and has destroyed oyster beds. Pollution has also made food from certain estuaries dangerous to eat.

Marine ecologists believe that estuaries have great potential for food production. The practice of "marine farming," called **mariculture** (mar'ə kul chər), is already well underway in Japan. Mariculture techniques make it possible

SCIENCE BACKGROUND

An interesting reference that includes a chapter on mariculture and its future potential is *The Great Ocean Business*, by Brenda Horsfield & Peter Bennet Stone, A Mentor Book / New American Library / Times Mirror, 1972.

MAIN IDEA

Pollution has damaged some estuary habitats. This is unfortunate, especially because these habitats may some day be needed for mariculture.



The harvesting of oysters, clams, and many types of fishes depends on keeping their natural habitat, the estuary, unpolluted.

ANSWERS TO CHECK YOUR FACTS

1. The salinity of a marine habitat is usually higher than that of a freshwater habitat and marine water is in constant motion and is interconnected throughout the world.
2. A mass of water that moves like a river through an ocean.
3. The vertical circulation of ocean water from the bottom toward the surface.
4. It returns to the surface the nutrients that settle to the bottom.
5. Plankton, nekton, benthos, neuston, and periphyton exist in both kinds of habitats.
6. Organisms that live in the open sea.

to increase the production of oysters, clams, and fish many times over what would occur naturally. As the world grows short of food the estuaries are likely to be the new frontier for a generation of new "farmers." This is another reason why marine ecologists wish people would develop more of an appreciation for estuaries.

CHECK YOUR FACTS

1. What are some characteristics of a marine habitat that distinguish it from a freshwater habitat?
2. What is an ocean current?
3. What is upwelling?
4. What is the ecological significance of upwelling?
5. What kinds of organisms are found in oceans as well as in freshwater habitats?
6. What are pelagic organisms?

SUMMARY

Oceans and seas cover about 70 percent of the earth. The marine habitat is the largest habitat. Water in the oceans is constantly in motion. Winds create upwelling, a vertical movement of water that helps circulate nutrients that have settled to the bottom. Marine organisms are classified in a manner similar to freshwater organisms. The intertidal zone is the area that is covered and uncovered by the tides. The region over the continental shelf is called the neritic zone. The oceanic zone refers to the part of the ocean beyond the continental shelf. The area where light can penetrate in the ocean is called the euphotic zone. Beneath it, where light cannot reach, is the aphotic zone.

REVIEW QUESTIONS

1. What is characteristic of the intertidal zone?
2. What forms the boundary between the neritic zone and the oceanic zone?
3. What vertical marine zone is found in the intertidal region?
4. What is the difference between the aphotic zone and the abyssal zone?
5. What kind of producer is present in freshwater habitats and generally absent in marine habitats?
6. What is the most common kind of producer in the ocean?
7. What is the difference between community structure in freshwater habitats and in marine habitats?
8. Why is the coral reef a unique community?
9. What is an estuary?

ANALYSIS AND APPLICATION

1. What groups of organisms are more common in the ocean communities than elsewhere? Identify some common organisms in each group.
2. Why would you be likely to find the same species of mackerel in the Atlantic and Pacific oceans but not likely to find the same species of trout in the rivers of North America and South America?

ANSWERS TO REVIEW QUESTIONS

1. It is along the shoreline and is not covered by water continuously.
2. The continental shelf defines the neritic zone beyond the intertidal zone. The oceanic zone begins beyond the shelf.
3. The euphotic zone.
4. Both are below the level of light penetration for photosynthesis, but the abyssal zone is the deepest part of an ocean.
5. The seed plant.
6. Phytoplankton.
7. There are more sessile organisms in the benthos of the sea than in fresh water; insects are found primarily in fresh water; and echinoderms are found only in the sea.
8. The organisms of the community make their own habitat.
9. A semienclosed coastal body of water that connects fresh water with the sea.

ANSWERS TO ANALYSIS AND APPLICATION

1. Red algae (Irish moss, laver); brown algae (rockweed, kelp); sponges; coelenterates (jellyfish, coral); mollusks (clam, snail); annelids (sandworm, leech); crustaceans (lobster, crab); echinoderms (starfish, sea urchin).
2. The oceans form a continuous habitat in which, ideally, an organism can travel throughout. Freshwater streams are discontinuous, and it is unlikely that fish could travel between them.
3. Estuaries are breeding grounds for many commercial and sport fishes. If we lose these production grounds, we also lose as a food source the dependent fishes that feed on producers living there.

47 *The Terrestrial*



OBJECTIVES

- To understand the nature of a terrestrial habitat and the basic ways in which it differs from an aquatic habitat
- To appreciate the limiting

factors on land and how they differ from those in water

- To know the definition of a biome
- To understand the unique characteristics of the following biomes: tundra, taiga, moist coniferous forest, temperate deciduous forest, temperate grasslands, tropical savanna, tropical rain forest, and desert

Habitat

47-1 General characteristics A **terrestrial habitat** is a land habitat. Terrestrial habitats have a greater variety than aquatic habitats. They range from mountains to lowland forests, and from grasslands to the arctic tundra.

47-2 Limiting factors One of the most important limiting factors on the land is not a factor in aquatic habitats. That limiting factor is water. Where there is water there is normally an abundance of organisms. Where there is little water there are usually few organisms. Where there is no water there is little or no life.

A second limiting factor is temperature. Temperature extremes in the air are much greater than in the aquatic habitat. They range from the almost furnacelike heat of sand deserts to the deep chilling cold of the arctic and antarctic.

A third limiting factor is the geographic barrier. A geographic barrier limits the movement of terrestrial populations. An example is the water barrier surrounding the continent of Australia. This barrier limits the populations that can enter or leave the terrestrial habitats on that continent.

47-3 The biomes Ecologists have classified the major terrestrial communities into units called **biomes** (bī'ōms). This classification is based upon many factors, including climate and the kind of biota. However, it is the type of climax vegetation that provides the name for most of the biomes. The climax vegetation is an indicator of the

MAIN IDEA

Terrestrial habitats are land habitats. They are more varied than aquatic habitats.

MAIN IDEA

Water is the most important limiting factor on land. Temperature and geographic features are other limiting factors.

SCIENCE BACKGROUND

Two other characteristics of the terrestrial habitat could be mentioned. One is the support structure needed by terrestrial animals that is not as necessary for aquatic animals, which are supported by the buoyant force of water. The other characteristic is the unique role of the soil.

MAIN IDEA

Major terrestrial communities are classified into biomes. The type of climax vegetation determines much of the other life found in the biome.

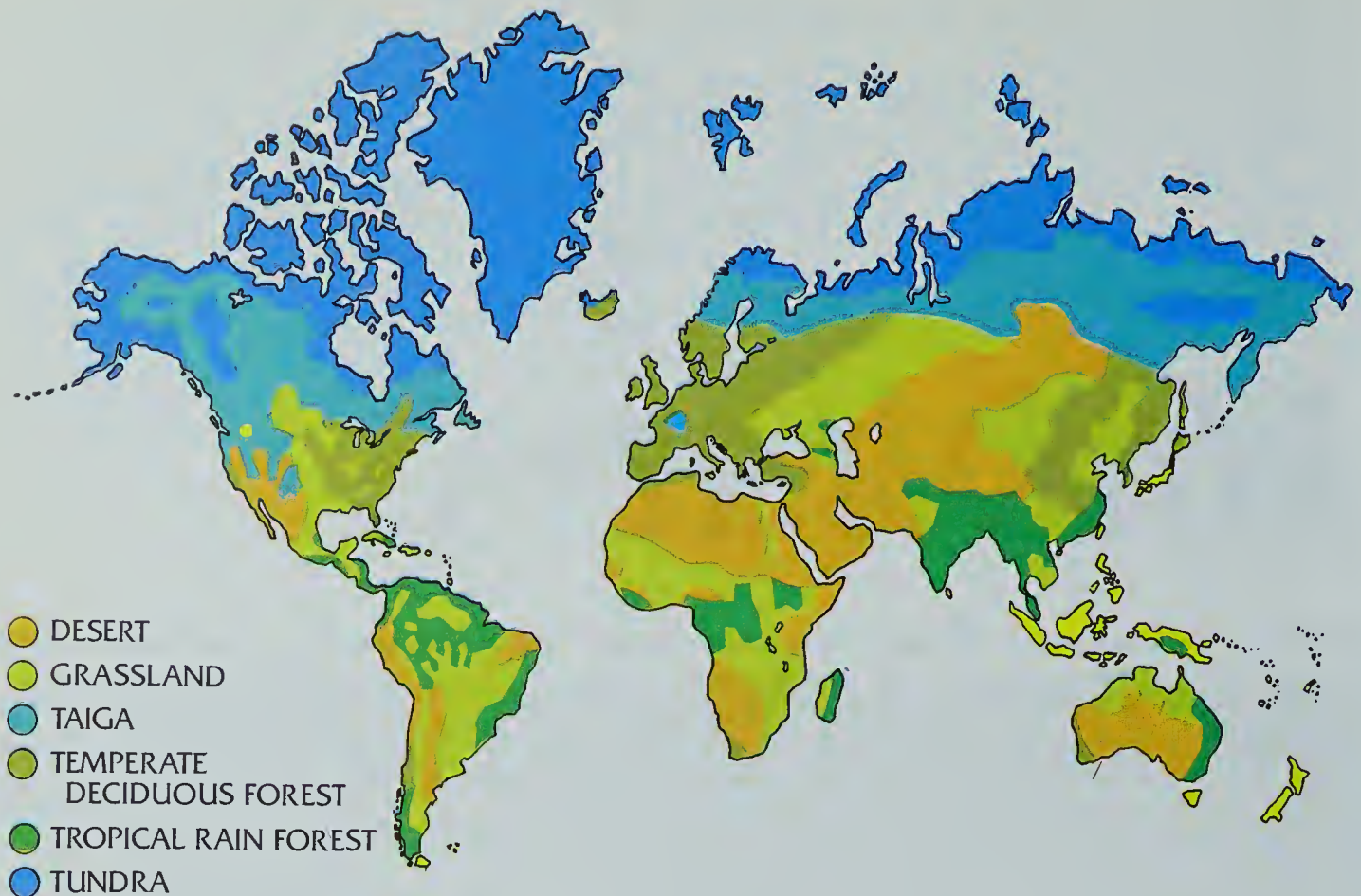


FIGURE 47–1

The major world biomes and their locations are indicated on this map.

MAIN IDEA

The tundra is a vast treeless plain. It covers much of the northern part of the world. Temperature and short growing seasons are the limiting factors of the tundra. Organisms with similar adaptations for filling similar niches are ecological equivalents.

type of climate. It is also one of the main factors that determine what other organisms live in the biome.

47–4 The tundra The **tundra** (tun'drə) is one of the few biomes that are not named after their climax vegetation. *Tundra* comes from a Finnish word meaning “treeless plain.” The tundra is a vast treeless plain that covers much of the northern part of the world. It is often called the arctic tundra because there is no similar biome in the antarctic region.

There are two main limiting factors in the tundra. One is low temperature and the other is a short growing season. Because of the low temperatures, only a thin upper layer of the soil thaws during the summer. Below that region, where the ground remains permanently frozen, the soil is called **permafrost** (pēr'mə frôst).

The main vegetation in the tundra is a mixture of grasses, low shrubs, and lichens. The animals include the caribou, reindeer, wolverine, musk-ox, arctic hare, arctic fox, and arctic ground squirrel. The caribou are the large grazing animals in the North American tundra. The rein-



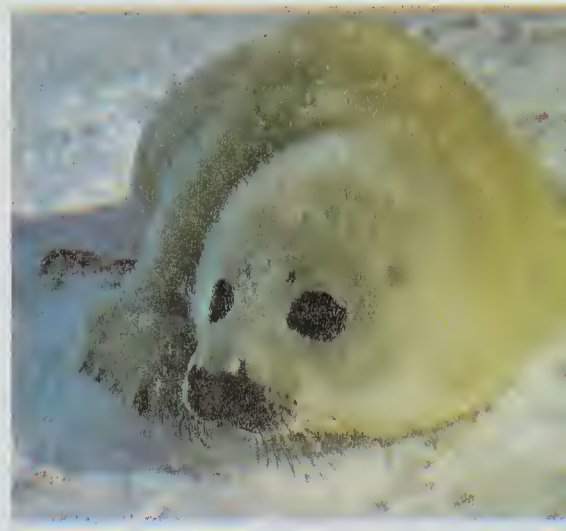
deer fill the same niche in northern Europe. The caribou and reindeer are an example of **ecological equivalents** (i kwiv'ə lənts), which are organisms with similar adaptations for filling similar niches.

There are very few invertebrates, amphibians, and reptiles in the tundra. The insects are limited in terms of different species. However, during the short summer a few species of insects create great suffering for humans and animals. There are the mosquitoes and biting flies (black flies and deer flies). They fly around in great swarms looking for food, which consists of blood from a warm-blooded animal.

47-5 The northern coniferous forest Below the tundra, in North America and Eurasia, there is a vast forest biome. It is called the **northern coniferous forest** or, after a Siberian word, **taiga** (tī gə). The climax vegetation is the conifers, most of which are spruce, fir, and pine. These conifers form a dense forest that shades the ground and prevents the growth of most smaller plants. Lichens, mosses, and a few shrubs and herbs man-

The caribou, an inhabitant of the tundra, feeds mainly on grasses, lichens, and mosses.

The arctic seas and nearby ice floes and land masses are home to the harp seal, a young pup of which is shown below.



SCIENCE BACKGROUND

Taiga is a Siberian word that is equivalent to "boreal forest" (northern forest).

MAIN IDEA

The moist temperate coniferous forest is somewhat warm and moist and contains huge conifers.

The northern coniferous forest is found in both the Western Hemisphere and the Eastern Hemisphere. Spruce, fir, and pine make up the climax vegetation.

age to survive in the **understory**, or region beneath the trees.

The animal life is more varied than in the tundra, with the moose, black bear, grizzly bear, grouse, squirrel, and a much greater variety of insects. Occasionally certain insect populations, such as bark beetles and budworms, multiply rapidly and destroy large areas of the forest.

The southern part of the taiga produces larger trees and has more economic importance than the northern taiga. This region still has great reserves of lumber.

47-6 Moist temperate coniferous forest A unique biome exists on the Pacific coastal region of North America. It stretches from central California to Alaska and is called the **moist temperate coniferous forest**. In this biome there are two limiting factors that are different from those in the taiga. The region gets much more moisture—up to 380 cm per year. In fact, it is often called a rain forest. The climate is much warmer and more favorable to plant growth. The result is a biome with huge trees, such as the redwood, and a lush growth of mosses, lichens, and smaller plants in the understory.





47-7 Temperate deciduous forests A **deciduous** (di sij'ü əs) **forest** is one where most of the trees lose their leaves in the fall. The **temperate deciduous forests** are found mostly in eastern North America and in Europe. In past centuries the trees of these forests were an important resource that helped develop the civilization. Therefore most of them have been cut or disturbed to some degree, and it is rare to find one in its natural condition.

The temperate deciduous forests are not continuous as are the tundra, taiga, and moist coniferous forest. There are a variety of communities, varying in rainfall, temperature, and climax vegetation.

47-8 Temperate grasslands **Temperate grasslands** are found on all continents except Africa. Grasses of different species are the climax plants. Most of the communities do not receive enough rainfall to grow trees. The original grasslands supported large herds of grazing animals, such as buffalo. Also burrowing animals, such as prairie dogs and badgers, were common. Now the native grasses are seldom observed. Many grasslands have been replaced with domestic grasses: wheat, oats, barley, corn. They have become farms, and the native grasses have mostly died out.

Once common on the temperate grasslands of North America, the bison was nearly driven to extinction. It was saved through careful conservation.

MAIN IDEA

The temperate deciduous forest contains trees that lose their leaves in the fall. Many of these forests have been damaged by civilization.

MAIN IDEA

Grasses are the climax vegetation in temperate grasslands. Grazing beyond the carrying capacity can lead to desertification, or the formation of a desert.

SCIENCE BACKGROUND

Some of the original grasslands were there probably because repeated fires kept trees out of the region. In the grasslands there are several zones, which are named for the size of the grasses that predominate—tall-grasses, midgrasses, and shortgrasses.

MAIN IDEA

Tropical savannas are grasslands with scattered trees. Rainfall is seasonal, and fires are common. Many grazers inhabit this biome. Much of this biome is threatened by overgrazing.

Some grasslands do not receive enough rainfall to support farm crops. These grasslands are used for livestock grazing. Such areas have to be managed according to their **carrying capacity**. The carrying capacity of a grassland is the maximum yield that it can produce year after year. If the carrying capacity is exceeded, overgrazing results. Overgrazing will eventually kill the grasses, including their tremendous root system. Their root system holds the soil in place. Without the root system of the grasses, the soil blows and drifts. Eventually, through a process called **desertification** (dez ə r tɪ f ə k ă 'shən), the grassland is changed into a desert.

47-9 Tropical savannas Tropical savannas are grasslands with scattered trees or clumps of trees. They are found in warm regions that receive up to 150 cm of rain per year. However, the rainfall is seasonal and there is a dry season, often with fires that kill the trees.

The tropical savanna of Africa has the largest number of grazing animals in the world. It is the home of the antelope, zebra, giraffe, and many others. It is also the home of a variety of well-known predators including the lion and leopard.

Grazing animals such as the giraffe and oryx inhabit the African savanna along with predators such as the lion.





This moist temperate coniferous forest of the North American Pacific coast, although often called a rain forest, differs from the true tropical rain forest.

Like any grassland, the tropical savannas can be destroyed by overgrazing. If cattle are introduced to replace the native animals, desertification could occur in the savanna. That is the worry of some African nations where the change from native animal to cattle has been made.

47–10 Tropical rain forests The **tropical rain forests** are forests of evergreen broad-leaved trees in low altitude regions near the equator. The seasonal temperatures vary less than the temperatures between night and day. The rainfall is high, averaging over 220 cm per year. The main rain forests are in the Amazon and Orinoco basins of South America, in central Africa, and in certain parts of Southeast Asia.

The tropical rain forests have a greater number of species than any other biome. For example, there may be more species of trees within a few acres of a tropical rain forest than throughout all of Europe. A characteristic of the animal life is that many of them are **arboreal** (är bôr'ē əl), or tree-living. Arboreal animals include chameleons, iguanas, snakes, frogs, and a variety of primates, such as monkeys, gibbons, and orangutans.

SCIENCE BACKGROUND

The emerging nations of Africa have ecological problems that will continue to create problems as they try to preserve the native wildlife, while advancing their economies and feeding their people. Desertification is a constant threat in the northern ranges of the savanna, and it is complicated because the possession of domestic grazing animals is a measure of status.

MAIN IDEA

Tropical rain forests are found at low altitudes near the equator. They have the most diversity of any biome. Many arboreal, or tree-living, animals live here. Tropical deciduous forests receive less rainfall than the rain forests.

This green python, an inhabitant of the tropical rain forest, is arboreal, as are many of the animals on which it preys.



SCIENCE TERMS

terrestrial habitat

biomes

tundra

permafrost

ecological equivalents

northern coniferous forest

taiga

understory

moist temperate

coniferous forest

deciduous forest

temperate deciduous forests

temperate grasslands

carrying capacity

desertification

tropical savannas

tropical rain forests

arboreal

tropical deciduous forest

deserts

succulent

chaparral

tropical scrub forest



Several types of plants, such as these cactus plants, are adapted to living in the dry environment of the desert.

SCIENCE BACKGROUND

The tropical rain forest represents most of the nutrient material of the region. When it is slashed and burned to produce agricultural land, the mineral residue serves as a fertilizer for a few crops, but then the land has to be abandoned and it becomes completely useless.

MAIN IDEA

Desert plants are adapted to survive with little water. Chaparrals receive winter rainfall and contain evergreens and shrubs. The tropical scrub forest is a biome intermediate between a desert and a savanna.

In regions that receive less rainfall than the tropical rain forest, an intermediate biome is usually recognized. This is the **tropical deciduous forest**, which is typical in the monsoon regions of India and Southeast Asia. The trees in the deciduous forest lose their leaves during the dry season instead of during the winter.

47–11 Deserts Deserts are dry lands that receive about 25 cm of rain or less per year. Some deserts, such as those in the central Sahara and in northern Chile, receive little or no rain.

There are three general types of plants in deserts. One is the annual that grows, reproduces, and dies within a short

time after moisture is present. The second type, called a **succulent** (suk'yə lənt), is a plant such as the cactus, which stores water in thick stems. The third is the desert shrub, with small leaves that can be shed during dry periods.

Deserts are often classified into three types on the basis of temperature. One is the hot desert—the Mohave Desert of southern California is an example. The second is the cool desert—such as the sagebrush lands of Nevada, Oregon, Alberta, and British Columbia. The third is the cold desert, as found in many parts of the Arctic.

There are two biomes that are borderline desert areas, but they have more rainfall. One is the **chaparral** (chap ə ral') biome, which receives good winter rainfall but little rain during the summer. This biome has evergreen trees and shrubs with thick leaves. Southern California and northern Mexico have large chaparral communities, many of which are now used for orchards. The **tropical scrub forest** is a biome with characteristics between desert and savanna. The tropical scrub forests receive uneven rainfall and have scattered trees that are often thorny and twisted.

Sagebrush is often the most prominent vegetation in the northern desert areas of the United States and Canada.

SCIENCE BACKGROUND

Deserts result from areas of persistent high pressure (the Sahara and the deserts of Australia); from the rain shadow of mountains (the deserts of western North America); or from high altitudes (the Gobi in Mongolia and the deserts of Tibet and Bolivia).

The creosote bush, the saguaro cactus, and the palo-verde tree are dominant in the hot desert of the southwestern United States.

Fire tends to prevent trees from taking over chaparral communities. Such areas are fragile and erode easily after occasional heavy rains causing mudslides.





The variation in the type of vegetation from the bottom to the top of a mountain is evident in the photograph above.

ANSWERS TO CHECK YOUR FACTS

1. A land habitat.
2. Water, temperature, and geographic barriers.
3. A unit of ecological classification of major community types into categories that are typified by a climax community.
4. The biome of the vast treeless plain of the Northern Hemisphere.
5. Low temperatures, short growing season, and permafrost.
6. Species that fill similar niches in similar ways in different parts of the world.
7. Examples—grasses, herbs, shrubs, and lichens, rabbits, foxes, reindeer, and wolverines.

47–12 Mountains Mountain regions cannot be classified into any single biome. Instead, a mountain range will have a variety of habitats that are characteristic of several biomes. At the bottom of the mountains there may be a desert or a moist coniferous forest. A little higher, because of the lower average temperature, there may be a grassland or a forest like the taiga. Still higher, at the timberline, there may be a region where grasses but no trees will grow. The region above the timberline may resemble the tundra in many ways.

CHECK YOUR FACTS

1. What is a terrestrial habitat?
2. What are the three environmental limiting factors of the land habitat?
3. What is a biome?
4. What is the tundra?
5. What factors limit the type of climax community in the tundra?
6. What are ecological equivalents?
7. What kinds of organisms live in the tundra community?

SUMMARY

Land habitats are terrestrial habitats. These habitats are much more varied than aquatic habitats. The most important limiting factor on land is the availability of water. Major terrestrial communities are grouped into biomes, which are usually named after the type of climax vegetation. The climax vegetation is an indicator of the climate and of the other organisms in the biome. The tundra is a treeless plain that covers much of the northern part of the world. The northern coniferous forest has more diversity than the tundra. The moist temperate coniferous forest is relatively moist and warm. Temperate deciduous forests have been largely eliminated by civilizations that needed space and resources. Mountain ranges usually have a variety of habitats characteristic of several biomes.

REVIEW QUESTIONS

1. What are the characteristics of the taiga or northern coniferous forest?
2. What is an understory?
3. How do the moist temperate coniferous forests differ from the taiga?
4. What is a deciduous forest?
5. How does the temperate deciduous forest biome differ from the biomes of the tundra, taiga, and moist temperate coniferous forest?
6. Where are the temperate grasslands found?
7. What is the carrying capacity of a range?
8. What is the danger of overgrazing?
9. How are tropical savannas different from temperate grasslands?
10. How are tropical rain forests and moist temperate coniferous forests different?

ANALYSIS AND APPLICATION

1. Explain why the tropical savannas contain the largest number of grazing animals in the world.
2. If the tropical rain forests contain the greatest variety of vegetation of all the biomes in the world, why have not people centered their civilizations in this biome?
3. In some mountain areas, forests are found only on the north-facing slopes and shrubs and grasses grow on the south slopes. How can these two different biomes both exist in a mountain area at the same altitude and under the same climatic conditions?

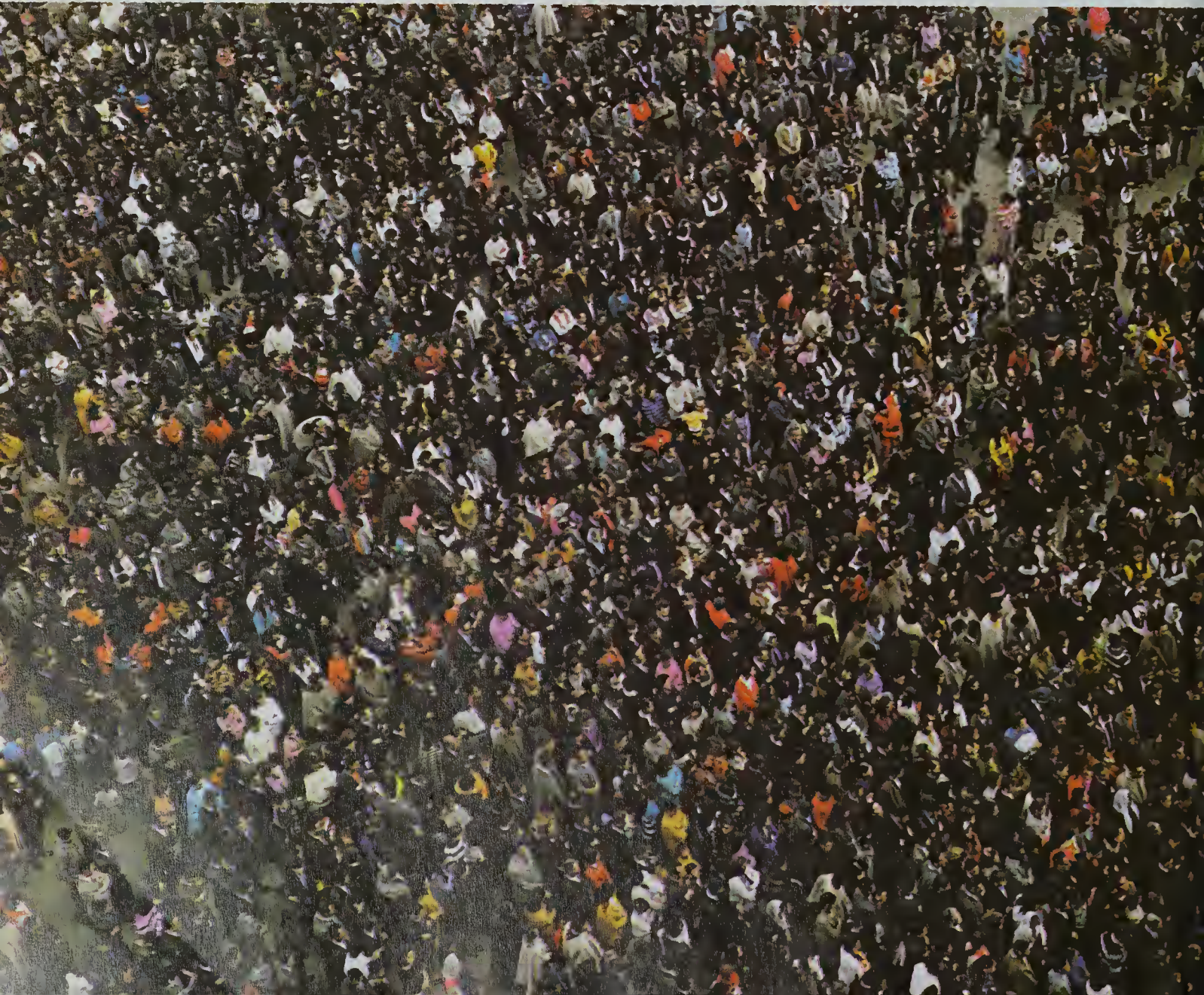
ANSWERS TO REVIEW QUESTIONS

1. Conifers dominate the forest. Lichens, moss, and a few shrubs and herbs grow as an understory.
2. A layer of vegetation below the canopy of a community.
3. They receive a greater amount of rain and are warmer.
4. A forest of trees that lose their leaves in the fall.
5. Temperate deciduous forests are discontinuous, unlike the other biomes, and they are found largely in eastern North America and in Europe.
6. On all continents except Africa.
7. The maximum ability of an area to support productivity yearly.
8. It depletes the carrying capacity of a range and can kill the range.
9. In savannas there are seasonal rains with dry seasons, and temperatures are warmer. There are also scattered trees.
10. In the rain forests the evergreens are broad-leaved trees instead of conifers, and the seasonal temperatures vary over a smaller range.

ANSWERS TO ANALYSIS AND APPLICATION

1. Grazing animals feed on herbs and grasses that are the main producers of savannas.
2. Although the variety and biomass of producers growing here is great, it is not a place that is easy for people to live in. The animals here live largely in the trees, and travel on the ground is hard because of the dense growth. Farming would be nearly impossible on a large scale.
3. North slopes often retain and make available more moisture than south slopes, where only shrubs and grasses grow.

48 *People and*



OBJECTIVES

- To understand the concept of exponential growth
- To know that the human population is growing at an annual approximate rate of 1.7 percent
- To appreciate two major concerns of ecologists with an exploding human population: deforestation and desertification
- To know that there is zero probability that the human population can continue to grow at its present rate, or at any rate, indefinitely
- To explain that limiting factors of some kind will in some way stop the growth of the human population
- To understand that ecologists cannot solve the problem of the growing human population

the Ecosphere

Ecology and the Human Population

48-1 A legend There is a legend that will help us explain how people are related to ecology. It is a legend of a Persian king who received a beautiful chessboard as a gift from a clever man. “How can I repay you?” asked the king. The clever man replied, “You can give me 1 grain of rice for the first square on the chessboard, 2 grains for the second square, 4 grains for the third square, and so on, doubling the rice for each of the sixty-four squares.” The king was happy to agree with the bargain. He brought rice from his stores, and his servants began counting out the grains. One for the first square, 2 for the second, 4 for the third, 8 for the fourth, and 16 for the fifth. They continued counting, with 128 on the eighth; 1 024 on the eleventh; 16 384 on the fifteenth; 524 288 on the twentieth; and 16 777 216 on the twenty-fifth. By the twenty-eighth square, the count reached over a thousand million, and by the fortieth square, a million million. Long before all sixty-four squares on the chessboard were used, the clever man had taken all the rice in Persia.

The legend of the Persian king is a good example of a growth pattern that must be understood. The pattern is called **exponential** (eks pō nen’shəl) **growth**. Exponential growth proceeds at a constant percentage of the whole over a constant period of time.

48-2 Exponential growth and people The human population is growing at an exponential rate. For example, the world population is growing at about 1.7

MAIN IDEA

Exponential growth proceeds at a constant percentage of the whole over a constant period of time.

SCIENCE BACKGROUND

To teach their children the nature of exponential growth, the French use an old riddle: A lily pond contains a single leaf. Each day the number of leaves doubles—two leaves the second day, four the third, eight the fourth, and so on. If the pond is full on the thirtieth day, at what point is it half full? The answer: on the twenty-ninth day.

MAIN IDEA

The human population is growing at an exponential rate of about 1.7 percent a year.



The rapid deforestation that often accompanies human population growth can make wood-gathering for cooking a difficult task.

SCIENCE BACKGROUND

One major problem in understanding the problem of human population growth is that a growth rate of 1.7 percent sounds minuscule. The calculations are deliberately placed in the body of the text so that students can appreciate the difference in the base figure and realize that 1.7 percent of 1 000 is a far different number from 1.7 percent of 4 thousand million.

MAIN IDEA

Declines in the growth rate do not necessarily signify an end to growth problems.

percent per year. Perhaps 1.7 percent does not seem to be a very high growth rate. But everything depends upon the base figure that is multiplied: 1.7 percent of 1 000 equals 17.

$$1\ 000 \times 0.017 = 17$$

And 1.7 percent of 1 000 000 equals 17 000.

$$1\ 000\ 000 \times 0.017 = 17\ 000$$

But 1.7 percent of 4 000 000 000, which is the approximate world population, equals 68 000 000.

$$4\ 000\ 000\ 000 \times 0.017 = 68\ 000\ 000$$

Stop and think what that really means. It means 68 million more human beings have to be fed, clothed, and housed every year. This is 186 301 more people every day!

$$68\ 000\ 000 \div 365 = 186\ 301$$

48-3 What if the growth rate declines? From time to time, the subject of the growing human population appears in newspapers or on television. The coverage is usually emphasized if there is any news of a declining rate of growth. *World Growth Rate Declines* is a typical headline, and such a headline is usually misunderstood.

Let us suppose that at some future time there is a dramatic drop in the population growth rate. Let's say that the rate drops from 1.7 percent to 1.5 percent. What would this mean in actual people? Here is the calculation:

$$4\ 000\ 000\ 000 \times 0.015 = 60\ 000\ 000$$

The 1.5 percent growth rate would mean 60 million more people per year, or 164 384 more people every day. That is still a tremendous number of people. It is enough to fill a city with 1 150 688 people every week!

48-4 Concerns of ecologists Ecologists are concerned about human population growth, which they call an “explosion.” They are concerned for several reasons.

They are concerned about **deforestation** (dē fôr ə stā’shən). This is the process by which forests are cut down without being replaced. Deforestation is occurring all over the world at a very rapid rate. Forests are being converted to farmland that will feed the exploding population. Forests are providing wood to build housing for the new people. And forests are being cut down for firewood. About one third of the world’s people use firewood for heating and cooking. But the ecological results have become disasters. Deforestation in the Himalaya Mountains has speeded up the runoff from rain and melting snow. Lowland rivers carry away tons of soil that have washed down. Floods are now common, and many thousands of people sometimes die from them.

A second concern of ecologists is the process of desertification. Throughout history, many societies have overgrazed their grasslands. They have exceeded the carrying capacity of the grasslands, killing the grasses and the roots that held the soil. Now, with an exploding population to feed, there is concern that the desertification rate will increase. With 60 to 80 million more people to feed each year, the pressure to overgraze will become much greater than it is now.

MAIN IDEA

Ecologists are concerned about deforestation and desertification—two processes that are destroying valuable resources, mostly under the pressure of a growing population.

SCIENCE BACKGROUND

Deforestation and desertification are just two examples of ecologists’ concerns. Two other major concerns are the overfishing of the oceans and the accumulation of pollution that will result from population increases.

There are many examples of deforestation. Forests that once covered one third of the total land area of Morocco, Tunisia, and Algeria were reduced to one tenth of the area by the middle of the twentieth century. The once lush island of Java now has only about 12 percent tree cover. The Philippines now have forests on less than 20 percent of their land area. The forests of northern Thailand are being reduced from 5 to 7 percent each year. It is expected that Nepal will be completely deforested by the end of the century, with predicted calamitous results on the subcontinent’s major river systems—the Indus, the Ganges, and the Brahmaputra.

Deforestation can increase the danger of floods that cause loss of human life and destruction of property and topsoil.



MAIN IDEA

Energy shortages will encourage deforestation, the sacrifice of potential fertilizers, and an increase in the use of draft animals.

SCIENCE BACKGROUND

Students should be alert to the two most basic facts about our exploding population: (1) that there is zero probability that the growth can continue; and (2) that limiting factors of some kind *will* stop the growth. Fortunately we still have choices regarding the limiting factors. There may be no choices for the children of today's students.

48-5 Energy complicates the concerns Most people now realize that the world is running out of cheap sources of energy. This complicates the ecological concerns that we have discussed. Consider what must happen to the people who depend on firewood for energy. Each year more people will want a decreasing supply of oil products.

Eventually many people will cut down all their forests and use up all the available firewood. What will they do then? They may do as many people in India are doing now. They may burn animal manure. However, this would create more problems. Animal manure is a valuable fertilizer on croplands. Burning destroys that value. The high cost of energy has put the cost of commercial fertilizer out of reach of these same people. To stay warm and to be able to cook their food, people have had to sacrifice the fertility of



While most people in North America are adequately nourished, many people throughout the world suffer from malnutrition.



Farming methods that utilize animals to till the land do not use up scarce fossil fuel. However, food for the animals may mean less for humans.

their croplands. But that leads to decreased crops at the time when more people need food. The result is hunger and eventual starvation.

Consider one more way the high cost of energy complicates and worsens ecological problems. About one third of the world's cropland is cultivated with draft animals, such as cows, water buffalo, and horses. These animals require a tremendous amount of food, much of it coming from grasslands. But it is unlikely that tractors or other gasoline-powered machinery will take their place. Because of the high cost of energy, people may have to depend more than ever upon draft animals. But what will that do? More draft animals will require more land and food. Much of that land and food will have to be subtracted from what is now used for humans. The net result again is hunger and more starvation.

48-6 Limiting factors and the S-curve The main concern of ecologists is the exploding human population and the S-curve. Most other populations grow slowly at first, as the human population did for many centuries. Then they reach a stage where the human population is

SCIENCE TERMS

exponential growth
deforestation

MAIN IDEA

Ecologists realize that the human population must encounter limiting factors in the near future, but they are unable to predict the nature of these limiting factors.

ANSWERS TO CHECK YOUR FACTS

1. The increasing rate of growth that proceeds at a constant percentage of the whole over a constant period of time.
2. The clearing of forests from the land without replanting trees.
3. Starvation and death because of insufficient food, space, and raw materials; wars over dwindling resources; and poisoning and starvation because of our own wastes.

ANSWERS TO REVIEW QUESTIONS

$$1. 4\,500\,000\,000 \times 0.02 = 90\,000\,000 \text{ people per year}$$

$$\frac{90\,000\,000 \text{ people}}{365 \text{ days}} = 246\,575$$

people per day

2. So many people are alive that a 50 percent decline (to 1 percent) still means that over 100 000 people are added each day.

$$4\,500\,000\,000 \times 0.01 = 45\,000\,000 \text{ people per year}$$

$$\frac{45\,000\,000 \text{ people}}{365 \text{ days}} = 123\,288$$

people per day

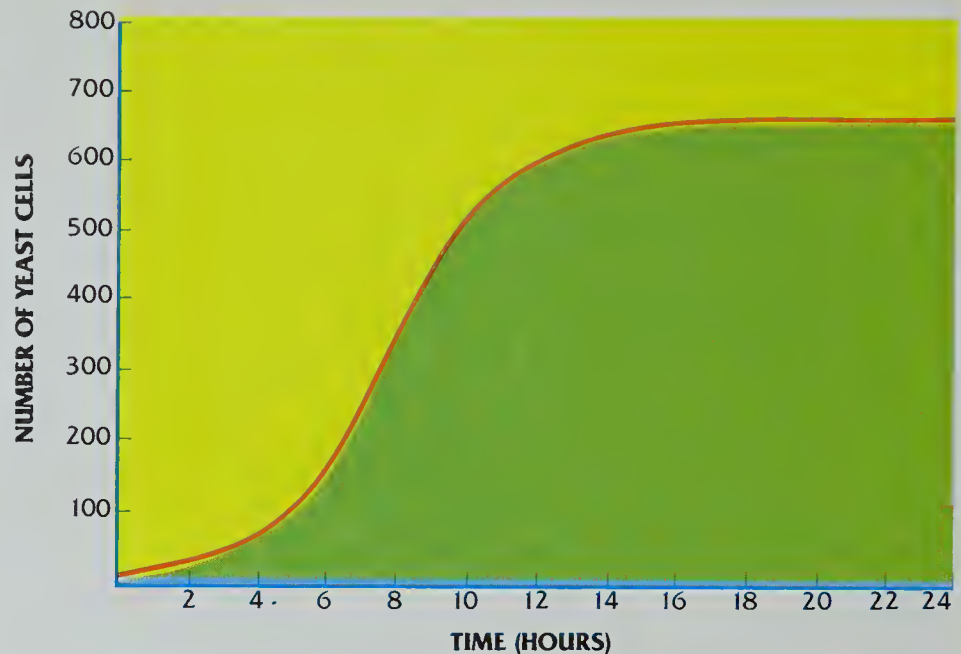


FIGURE 48-1

A growth curve for a population of yeasts is graphed above. Limiting factors always act to control population size.

right now, where there is very rapid growth. But other populations always face limiting factors that slow the growth and cause the growth curve to level out again. Will this happen to the human population?

Ecologists believe there is zero probability that the human population can continue to grow at the present rate. Eventually the earth would become stacked with people, but we would be out of resources long before then. So there is only one other probable thing that can happen. Limiting factors of some kind will slow the population growth rate. But what will the limiting factors be?

Will they be starvation and disease? Will they be deaths from wars over dwindling resources? Will they be from accumulated wastes and pollution? What are the other possibilities? The ecologist can only tell us that limiting factors always check the growth of populations. The choice and management of limiting factors on the human population is in the hands of all people. The ecologist can only educate. The people in general are the ones who must make choices and take actions.

You have now been educated. You now know about the exploding population and that limiting factors must eventually stop this growth pattern. What limiting factors would you prefer to see in operation? At this time, there is still a choice. But with 186 301 more people tomorrow, and 186 301 more people the next day . . . ???

CHECK YOUR FACTS

1. What is exponential growth?
2. What is deforestation?
3. What factors may limit the growth of the world population?

SUMMARY

The pattern of exponential growth can generate enormous numbers in a surprisingly short time. The human population is growing exponentially at a rate of about 2 percent a year. Even if this rate declines, hundreds of thousands of humans will be added to the population every week. Ecologists are concerned about deforestation. This occurs as people need more space and resources. Valuable grazing lands are also being destroyed by overgrazing. As more food is needed the pressure to overgraze becomes greater. Energy shortages will probably encourage additional deforestation as people use wood for energy. Certain limiting factors normally operate to slow the population growth of species.

REVIEW QUESTIONS

1. What would a 2 percent increase in world population represent in the number of new people each day if the world population at the present time is determined to be 4.5 thousand million people?
2. How many people would be added daily to the human population even if the world growth rate were to drop as much as 50 percent?
3. What is a population explosion?
4. How does the size of the world population influence the rate of deforestation?
5. What are the dangers of deforestation?
6. What is desertification and how does it occur?

ANALYSIS AND APPLICATION

1. How does the high cost of energy complicate and worsen human ecological problems?
2. Once the processes of desertification and deforestation occur, why is it very unlikely that the biomes can be reestablished right away?
3. Is there any chance that the world population could somehow continue to increase at the present rate forever? Give a reason for your answer.

3. The rapid growth or exponential growth phase of a population.
4. Trees are cut to supply wood to burn, to build needed materials, and to clear land for raising food. More people mean more trees must be cut for all these needs.
5. Soil erosion and runoff are greater when there are no trees to hold the soil. Loss of soil and nutrients, and the danger of flood results.
6. The conversion of grasslands to deserts by overgrazing, which results in the death of grasses that hold the soil in place.

ANSWERS TO ANALYSIS AND APPLICATION

1. It makes fossil fuels nearly unavailable for fertilizer production, thus reducing our food production. It drives people to alternate fuel sources, such as firewood, which in turn robs the ecosystem of its natural source of fertilizers, again cutting the possible food productivity of the world. Using draft animals instead of fuel-eating tractors increases the food needs of the world, since the animals must eat, too.
2. When the influence of the biota on the physical environment is lost, the debris of dead organisms no longer feeds consumers who release raw materials to the soil again. Soil does not have organisms tying it down against wind and water, so it is more susceptible to erosion. Once the soil is lost, producers will not be able to grow there as successfully, if at all.
3. No. We will run out of the essentials for life. Mortality will increase when food and nutrients and space run out, and the chance of new births will be reduced.

UNIT 8 REVIEW

1. What is the difference between an ecosystem and a habitat?
2. List some of the limiting factors on the size of a population of organisms.
3. Prepare a simple food chain showing the relationship between at least four different organisms.
4. Define the following terms: symbiosis, parasitism, commensalism, mutualism.
5. How are decomposers important to the web of life?
6. Explain the relationship between respiration and photosynthesis in the oxygen cycle.
7. What is the difference between nitrogen fixation and denitrification? Why are they both important processes?
8. State the competitive exclusion principle. How does this principle help explain the process of succession?
9. Discuss the three zones that exist within lentic communities.
10. Oil spills in the ocean can seriously endanger sections of the marine habitat. Find out what steps are being taken to develop new methods of dealing with such oil spills.
11. Discuss the horizontal and vertical zonation of the marine habitat.
12. Cities and farmlands have replaced most of the natural communities in many biomes. However, the original populations often still exist to a lesser degree. Try to determine the type of biome that your living area is part of, even if much of the natural biota has been eliminated.
13. Why do mountain ranges show a variety of biomes instead of simply one?
14. Prepare a report on the possible hazards to the environment that might be caused by the release of fluorocarbon compounds into the atmosphere.

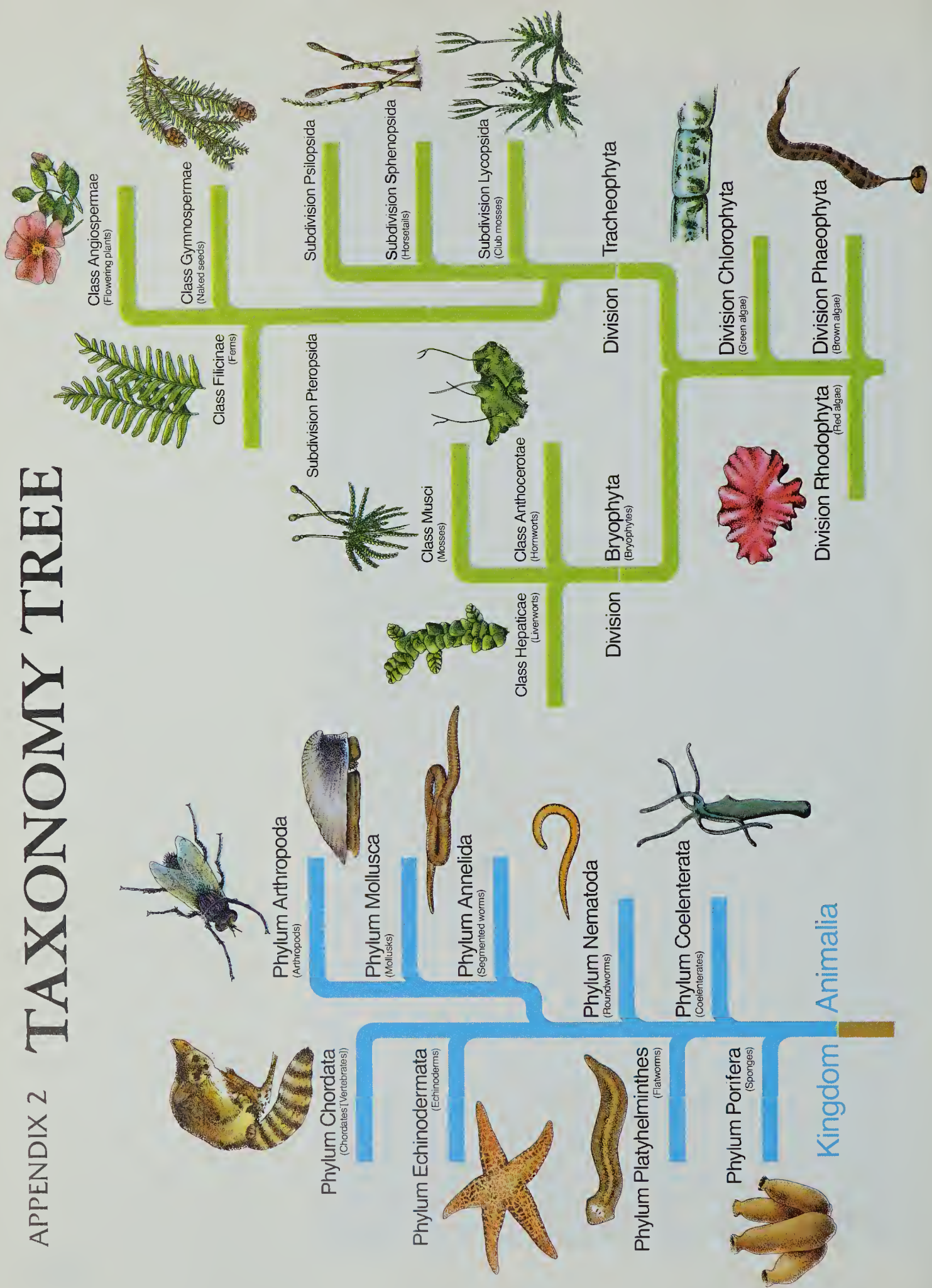
Kilojoule Guide for Some Common Foods

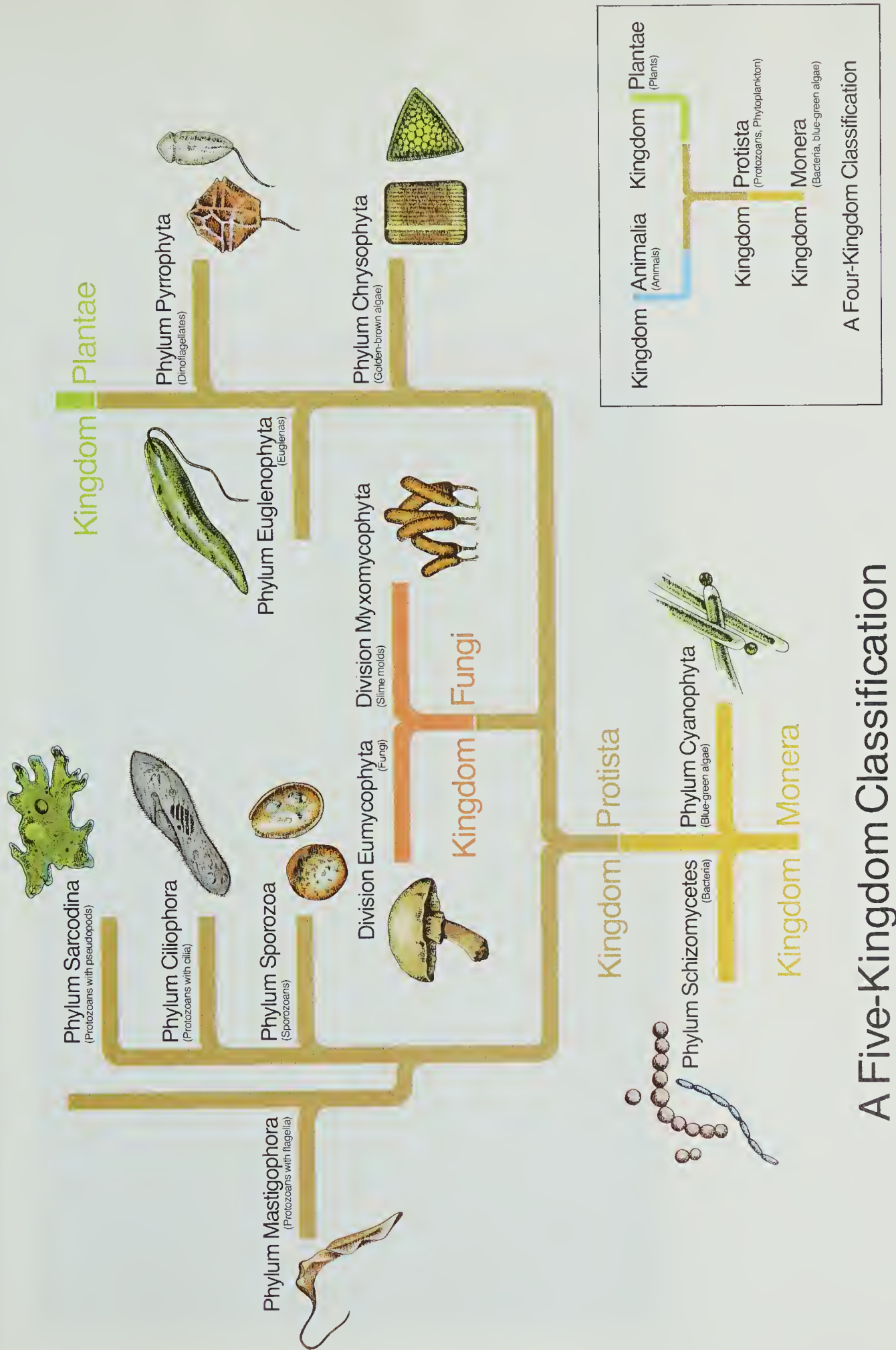
<i>Food</i>	<i>Quantity</i>	<i>Kilojoules</i>
<i>Beverages</i>		
Chocolate-flavored drink made with milk	180 mL	874
Chocolate-flavored drink made with water	180 mL	571
Chocolate milk shake	240 mL	1768
Cocoa with milk	180 mL	1029
Coffee with sugar and milk	250 mL (1 cup)	126
Cola drinks—diet	180 mL	4.2 to 16.8
Cola drinks—sweetened	180 mL	328
Ice-cream soda	240 mL	966
Orange juice—fresh	240 mL	462
Skim milk—fortified	240 mL	609
Tomato juice	240 mL	189
Whole milk	240 mL	672
<i>Breads</i>		
Bran muffin	1	475
English muffin	1	567
Frankfurter roll	1	504
French bread	1 slice	244
Italian bread	1 slice	231
White bread	1 slice	273
<i>Cereals and Pasta</i>		
Corn flakes—plain	250 mL (1 cup)	420
Corn flakes—sugared	250 mL (1 cup)	651
Oatmeal	250 mL (1 cup)	546
Pizza with cheese	1 slice	777
Shredded wheat	1 biscuit	378
Spaghetti with tomato sauce and cheese	250 mL (1 cup)	1092
<i>Candy</i>		
Candy bar	43 g to 71 g	588 to 1411
<i>Dairy Products</i>		
Cottage cheese—creamed	28 g	126

<i>Food</i>	<i>Quantity</i>	<i>Kilojoules</i>
Cream cheese	28 g	445
Ice cream	1 large scoop	630 to 1050
Ice milk	1 large scoop	420 to 630
Sugar cone	1	189
Swiss cheese	28 g	441
<i>Desserts</i>		
Brownie with nuts	1	399
Cake—angel food	1 small slice	567
Chocolate-chip cookies	1 cookie	210
Chocolate pudding	125 mL (½ cup)	806
Cupcake—iced	1	546
Pie	1 average piece	1260 to 1890
<i>Eggs</i>		
Eggs—fried	1	517
Egg—soft-boiled or poached	1	336
<i>Fish and Seafood</i>		
Fish sticks—breaded	114 g	840
Haddock—fried	114 g	794
Lobster—broiled	114 g	433
Oysters—raw	114 g	315
Shrimp—boiled or broiled	114 g	433
<i>Fruit</i>		
Apple—fresh	1	294
Banana—fresh	1	420
Cantaloupe—fresh	½ melon	252
Orange—fresh	1	273
Peach—fresh	1	147
Strawberries—fresh	125 mL (½ cup)	118
Watermelon—fresh	1 average slice	483
<i>Meat and Poultry</i>		
Beef—braised	85 g	1029
Chicken—broiled	85 g	483
Duck—roasted	85 g	954
Frankfurter—boiled	1	714
Hamburger—lean and broiled	85 g	772
Lamb chop—lean and broiled	85 g	743
Pork chops—lean and broiled	85 g	962
Salami	28 g	370
Steak—sirloin, broiled	85 g	1050

<i>Food</i>	<i>Quantity</i>	<i>Kilojoules</i>
<i>Nuts</i>		
Cashews	6	353
Peanuts—roasted	28 g	441
Pistachios	30	370
<i>Salads</i>		
Chicken	1 average helping	848
Coleslaw	1 average helping	693
Potato	1 average helping	458
Salad dressing— mayonnaise	15 mL (1 tablespoon)	420
Salad dressing— Thousand Island	15 mL (1 tablespoon)	336
Tossed green—no dressing	1 average helping	84
<i>Sandwiches</i>		
Bacon, lettuce, and tomato	1	1134
Cheeseburger	1	1722
Chicken salad	1	1352
Egg salad	1	1407
Frankfurter	1	1218
Grilled cheese	1	1596
Ham and cheese	1	1243
Hamburger	1	1281
Peanut butter and jelly	1	1445
Tuna	1	945
<i>Snacks</i>		
Potato chips	1 large	46
Pretzels—twisted	1 large	252
Saltine crackers	1	50
<i>Soups</i>		
Onion	250 mL (1 cup)	248
Pea	250 mL (1 cup)	609
Tomato—with water	250 mL (1 cup)	378
<i>TV Dinners</i>		
All types of TV dinners	1	1470 to 2100
<i>Vegetables</i>		
Carrots—fresh	125 mL (½ cup)	97
Lettuce—fresh	2 leaves	42
Potato—baked	1 medium	378
Potato—boiled	1 small	168
Potato—french fried	10 pieces	651
Potatoes—mashed	125 mL (½ cup)	265
Radishes—fresh	4 small	21
Tomatoes	1 medium	168

TAXONOMY TREE





A Five-Kingdom Classification

Biology-Related Occupations

<i>Occupation</i>	<i>Training/Education</i>	<i>Job Description</i>
Animal Laboratory Assistant	On-the-job	Feeds and cares for laboratory animals and equipment
Biologist	B.Sc., M.Sc. Ph.D.	Carries out research centering around living organisms. Many are specialists (e.g., geneticist, microbiologist, biochemist)
Biomedical Engineer	B.Sc., M.Sc.	Applies engineering skills and methods to solving medical problems, including the design of special equipment
Biostatistician	B.Sc., M.Sc., Ph. D.	Applies mathematics and statistics to research problems related to health care
Cytotechnologist	2–3 years college and a 1-year program	Checks slides of human cells for cancerous growths

<i>Occupation</i>	<i>Training/Education</i>	<i>Job Description</i>
Dental Hygienist	Dental Hygiene School	Examines and cleans teeth; gives fluoride treatments; instructs patient in good dental hygiene
Dental Technician	On-the-job	Prepares dentures, crowns, and bridges
Dentist	Dental School, D.D.S.	Diagnoses and treats oral disorders such as tooth decay and gum disease
Dietitian	B.S., traineeship	Manages food service; plans menus; instructs people in proper diet
Environmentalist	B.Sc., M.Sc.	Develops and implements systems to improve the quality of the air, water, and other environmental conditions

<i>Occupation</i>	<i>Training/Education</i>	<i>Job Description</i>
Food Technologist	B.Sc., M.Sc.	Investigates and improves the production, processing, shipping, and utilization of food
Forester	B.Sc.	Manages and develops forests
Health Sciences Librarian	M.L.Sc.	Specializes in health and medical information
Histological Technician	1-year training program	Cuts, stains, and mounts body tissues for microscopic examination
Horticulturalist	B.Sc., M.Sc.	Raises plants and attempts to improve the characteristics of fruits, vegetables, and flowers
Medical Illustrator	B.Sc.	Produces drawings and graphics of the human body for scientific media
Medical Laboratory Assistant	On-the-job	Performs routine tests, such as blood typing, under supervision

<i>Occupation</i>	<i>Training/Education</i>	<i>Job Description</i>
Medical Laboratory Technician	2-year associate degree	Performs medical tests, such as bacterial identification, under supervision
Medical Technologist	B.Sc. and special training	Supervises assistants and technicians; performs more complex medical tests
Nurse, licensed practical	High school plus 1-year program	Administers routine nursing care and assists the registered nurse
Nurse, registered	Nursing School	Administers drugs and medical treatments under the supervision of a physician; monitors patients' progress; often specialized
Optometrist	College of Optometry	Examines eyes for vision problems; prescribes corrective lenses and exercises
Pharmacist	College of Pharmacy	Fills prescriptions for drugs and medicines prescribed by physicians

<i>Occupation</i>	<i>Training/Education</i>	<i>Job Description</i>
Physical Therapist	School of Physical Therapy	Plans and provides treatment to rehabilitate people with disabling disorders
Physician	Medical School, M.D.	Diagnoses and treats human diseases and disorders; frequently specialized
Physician's Assistant	2-year program, some college or experience in medical care	Performs routine examinations; administers drugs and treatments prescribed by a physician
Soil Conservationist	B.Sc., M.Sc.	Provides technical assistance to farmers to conserve and improve soil
Toxicologist	B.Sc., M.Sc.	Investigates chemical compounds for poisonous properties and how these affect health
Veterinarian	Veterinary School, D.V.M.	Diagnoses and treats diseases and disorders in animals
X-ray Technologist	2-year program	Takes X rays of patients to diagnose illness and injury

Cellular Respiration

The cells in your body, as well as most other cells, carry on a process called cellular respiration. These cells have the ability to break down a molecule of glucose into molecules of carbon dioxide and water. In this process, 38 ATP molecules are produced. The energy stored in these ATP molecules is available for use by the cell. The energy conversion efficiency of cellular respiration is approximately 60 percent. This means that about 60 percent of the energy stored in the glucose molecule is transferred to ATP molecules. The remaining energy is released as heat. In comparison, the efficiency of the automobile engine in converting the energy in gasoline to usage energy is about 30 percent. Thus the cell is about twice as efficient as one of our favorite and most efficient machines.

Cellular respiration involves a total of 140 chemical reactions. These reactions are controlled by enzymes and coenzymes. Enzymes, you will recall, are large protein molecules that enable chemical reactions to occur with a minimum of activation energy. The chemical name for such a molecule is *catalyst*. Enzymes are protein molecules that function as catalysts. Coenzymes are nonprotein molecules that function in conjunction with enzymes. Some of the coenzymes are derivatives of the B complex vitamins—niacin, riboflavin, and thiamine.

The chemical reactions involved in cellular respiration occur in a series of steps. For example, step B always follows step A and step C always follows step B. The enzymes and coenzymes that control a particular step are always in close physical position to those controlling the preceding step and the following step. It may help to think of cellular respiration as a factory “disassembly line.” The glucose molecule is passed from one worker with tools (an enzyme with its coenzyme) to another worker with tools (another enzyme with its coenzyme). As the glucose molecule moves along the “disassembly line” it is gradually taken apart. The carbon, hydrogen, and oxygen atoms that make up glucose eventually end up as carbon dioxide and water.

However, there are a number of intermediate molecules manufactured before the carbon dioxide and water are made. Also, at the end of the “disassembly line” there is a bonus for all “workers” in the cell. These are the 38 ATP molecules that are gained from the energy stored in the bonds of glucose.

There are actually three series of chemical reactions that break down glucose and produce ATP. Each series of reactions is called a metabolic pathway. Therefore the “disassembly line” is really made up of three “sub-disassembly lines.”

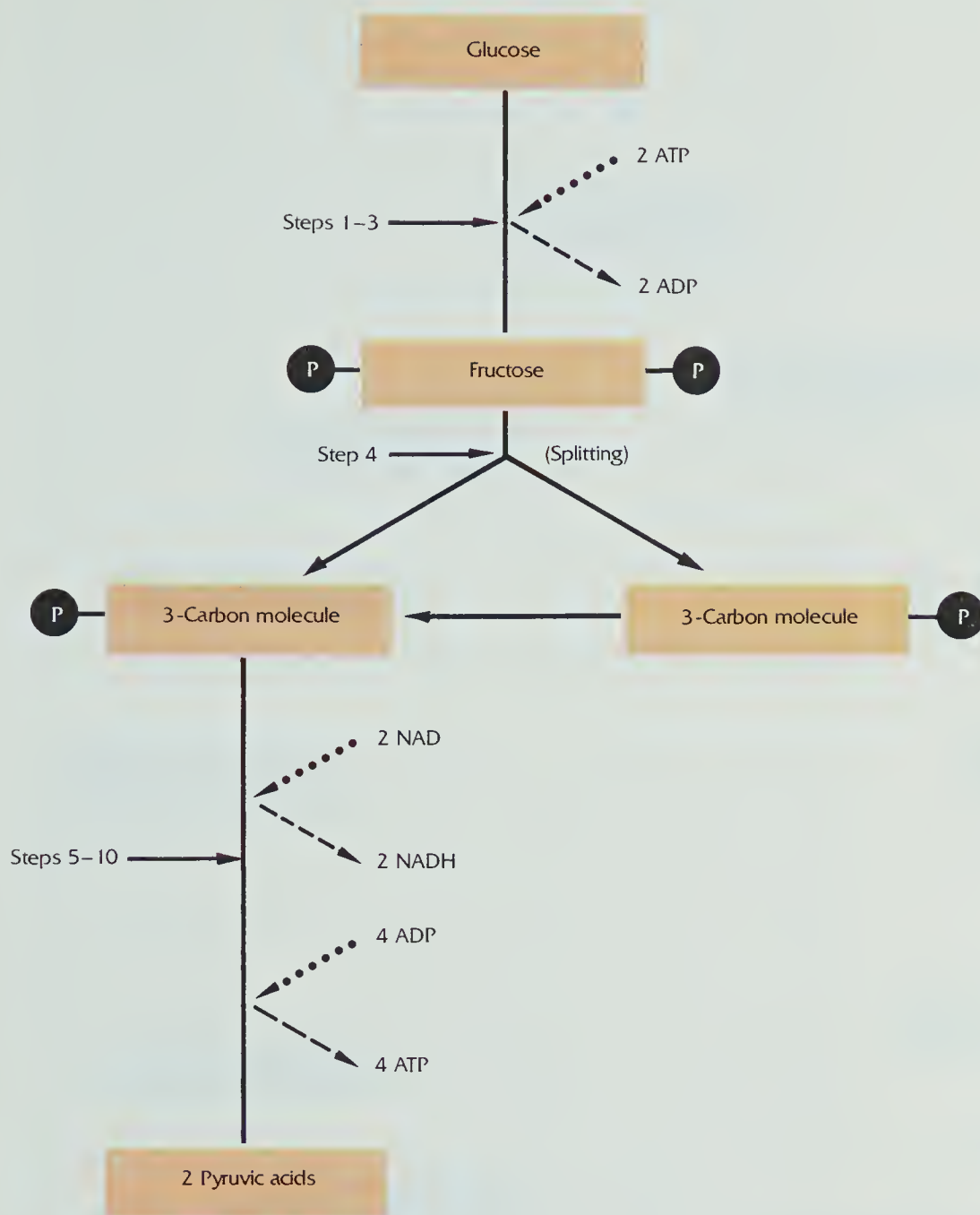
Most of the reactions in the three metabolic pathways are oxidation-reduction reactions. An oxidation reaction is one that removes an electron from a molecule. A reduction reaction is one that adds an electron to a molecule. In cells, an oxidation or reduction reaction usually involves the transfer of a hydrogen atom, which has one electron. Glucose is completely oxidized during cellular respiration. Therefore all 12 of the hydrogen atoms that make up glucose are removed and transferred to other molecules. These other molecules are reduced because hydrogen atoms (with their electrons) have been added to them. The overall reaction for the oxidation of glucose is:



Glycolysis The first of the three metabolic pathways is **glycolysis**. (Glycolysis is also called anaerobic respiration.) There are ten steps and ten different enzymes involved in the glycolysis pathway. The overall pathway is illustrated in Figure 1. In the first three steps, the phosphates from two ATP molecules are added to the glucose molecule. The glucose molecule is also rearranged to form a different, but similar, 6-carbon sugar molecule called *fructose*. This new molecule is more unstable and “more ready” for disassembly because of the addition of the high-energy phosphate groups.

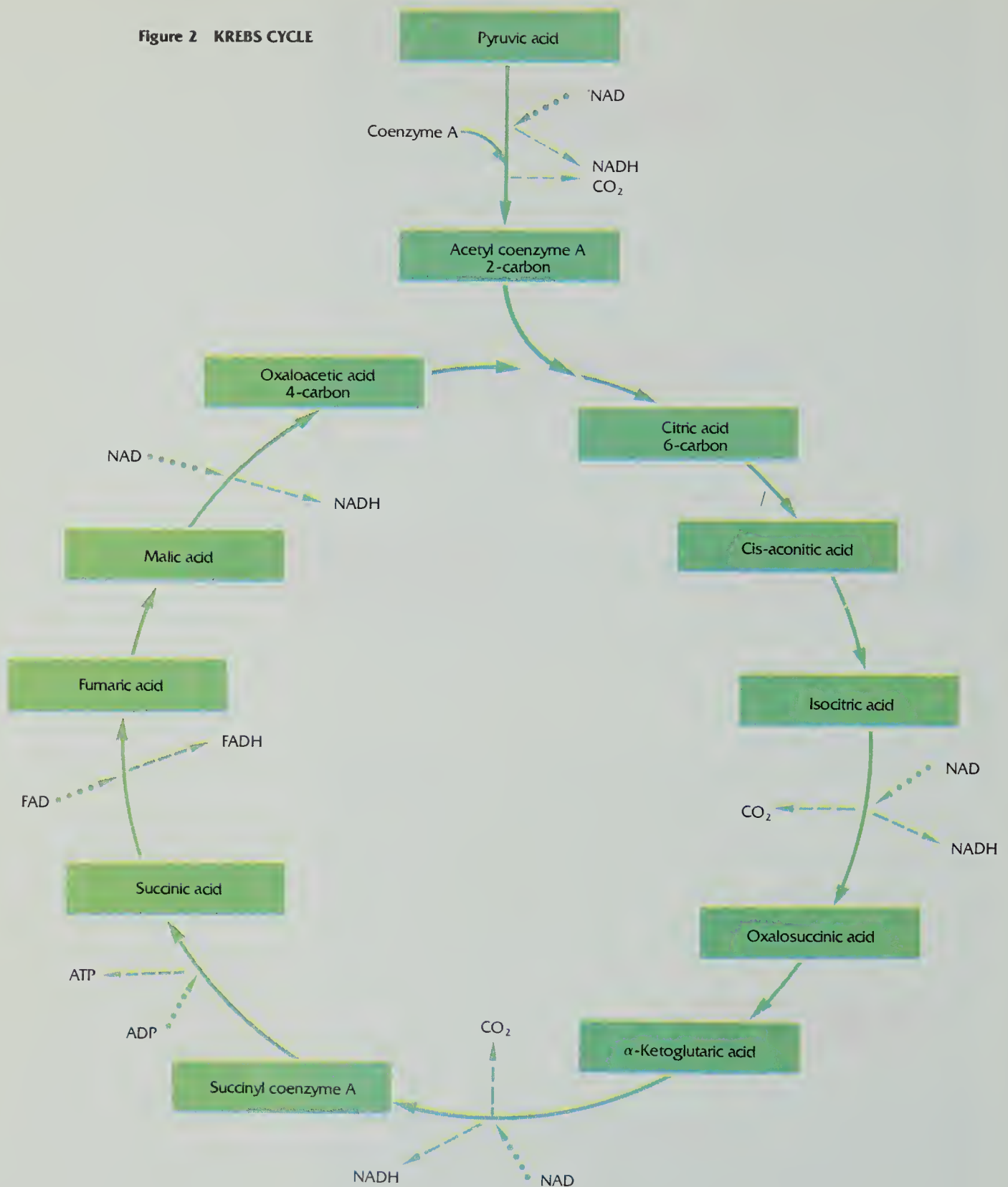
In step four, the 6-carbon sugar fructose is broken into two 3-carbon molecules. Then, in steps five through ten, each 3-carbon molecule is oxidized and changed to pyruvic acid, which is also a 3-carbon molecule. In the process, two molecules of a coenzyme named *nicotinamide adenine dinucleotide* (abbreviated NAD and derived from the B vitamin niacin) are reduced and become NADH. Also in the process, four ATP molecules are produced. Since two ATP’s were used to start the reactions, the net gain in energy for the cell is two ATP’s. This is less than 10 percent of the energy stored in glucose.

Figure 1 GLYCOLYSIS (Anaerobic respiration)



Krebs Cycle Following glycolysis, two molecules of pyruvic acid still remain. Most cells have the ability to continue the breakdown of pyruvic acid into carbon dioxide and water. The complete process, called aerobic respiration, involves the two remaining metabolic pathways. Both occur inside the mitochondrion. The first metabolic pathway is called the **Krebs cycle**. (It is also called the citric acid cycle after one of the key molecules produce during the reactions.) The Krebs cycle is illustrated in Figure 2.

Figure 2 KREBS CYCLE



Two important processes occur in the Krebs cycle. First, pyruvic acid is broken down into carbon dioxide molecules. Second, and more important from an energy standpoint, coenzymes are reduced (hydrogen is added) and made ready for the second metabolic pathway.

The first step in the Krebs cycle is the conversion of pyruvic acid to acetyl coenzyme A, a 2-carbon molecule. In the process, one molecule each of NADH and CO₂ is produced. The acetyl coenzyme A then combines with a 4-carbon molecule of oxaloacetic acid to form citric acid, a 6-carbon molecule. Then a series of enzymes oxidizes the citric acid, producing, stepwise, several more molecules. (They are, in order, cis-aconitic acid, isocitric acid, oxalosuccinic acid, alpha-ketoglutaric acid, succinyl coenzyme A, succinic acid, fumaric acid, and malic acid.) Finally, a 4-carbon molecule of oxaloacetic acid is produced. Then the process is repeated in another cycle when oxaloacetic acid is combined with another molecule of acetyl coenzyme A to form the 6-carbon molecule of citric acid.

During each “turn” of the cycle, three molecules of the coenzyme NAD and one molecule of the coenzyme FAD are reduced. (FAD is *flavin adenine dinucleotide*, a coenzyme derived from the B vitamin riboflavin.) Also, two molecules of CO₂ and one molecule of ATP are produced during each “turn” of the cycle. Two “turns” of the cycle are necessary to completely oxidize the two molecules of pyruvic acid produced during glycolysis.

Oxidative Phosphorylation The third metabolic pathway in cellular respiration is the oxidative phosphorylation pathway. This pathway involves two series of enzymes embedded in the cristae, the inner membranes, or cross-walls, of the mitochondrion. One series of enzymes is responsible for the stepwise transfer of the electrons from the reduced coenzymes NADH and FADH to a series of electron acceptors. This is called the electron transport chain. With each transfer the energy level of the electrons becomes lower. The energy that is given up is used by the second series of enzymes in the production of ATP. This second group of enzymes, called the F₁ enzymes, can actually be seen in electron micrographs of the cristae. They appear as a “ball on a stick” extending from the inner surfaces of the cristae. The F₁ enzymes take the energy from the electrons in the electron transport chain and use that energy to phosphorylate ADP. *Phosphorylate* is the technical name for the process already mentioned several times, the process in which a phosphate group is added to ADP, producing ATP. The electrons (hydrogen atoms) in the electron transport chain are eventually transferred to oxygen, and water molecules are formed. This completes the reactions in the oxidative phosphorylation pathway. Note that oxygen must be present in the mitochondrion; this is the reason why practically all organisms must have oxygen.

A total of 34 ATP molecules result when all the reduced coenzymes from two “turns” of the Krebs cycle are passed through the oxidative phosphorylation pathway. The net gain by the cell, from the complete breakdown of glucose through the three metabolic pathways, is as follows:

PATHWAY	ATP's PRODUCED
Glycolysis	2
Krebs cycle (two “turns”)	2
Oxidative phosphorylation	<u>34</u>
TOTAL	38

Other Molecules Glucose is not the only molecule that is broken down and has its energy transferred to ATP by the cell. Fatty acids (components of fats) and amino acids (components of proteins) are also disassembled and the energy used to phosphorylate ADP and make ATP.

The Krebs cycle also has another function besides preparing reduced coenzymes that go into ATP production. Many of the intermediate molecules formed during the Krebs cycle can serve as “skeletons” for new molecules needed by the cell. For example, in a growing body, many types of molecules are needed—nucleic acids, fats, proteins, and so on. There are other metabolic pathways in the cell that can use the intermediate molecules produced during the Krebs cycle as “skeletons” on which these new molecules can be built.

GLOSSARY

Key to Pronunciation

a	hat, cap	ng	long, bring	ù	full, put
ā	age, face	o	hot, rock	ü	rule, move
ā	care, air	ō	open, go	zh	measure, seizure
ä	father, far	ô	order, all		
ch	child, much	oi	oil, voice	ə	represents:
e	let, best	ou	house, out	a	in about
ē	equal, see	sh	she, rush	e	in taken
ēr	term, learn	th	thin, both	i	in pencil
i	it, pin	TH	then, smooth	o	in lemon
ī	ice, five	u	cup, butter	u	in circus

The Key to Pronunciation is from THE WORLD BOOK DICTIONARY.

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The numbers in parentheses following each definition indicate the chapter and section in which the term is introduced.

abiotic (ā bī ot'ik) Lifeless; nonliving. (41-7)

abscission (ab sizh'ən) The falling of mature fruit, stems, or leaves from trees. (23-4)

absorption (ab sôrp'shən) In digestion, the movement of dissolved food or other substances into the blood stream by osmosis, diffusion, or other processes. (33-1)

abyssal (ə bis'al) **zone** The very deepest part of a marine habitat, ranging from 2 000 to 5 000 m below the surface. (46-3)

acetylcholine (as'ə təl kō'lēn) A chemical transmitter that bridges the gap in a synapse, forming a chemical link between the end of one axon and the beginning of the next dendrite; an impulse transmitter of a nerve cell. (37-3)

acromegaly (ak rō mæg'ə lē) Hypersecretion of growth hormone in adulthood, which causes an enlarged jaw and brow, and sometimes a humped back. (36-3)

actin (ak'tin) Bundles of slender filaments that together with myosin compose the myofibrils in muscle fiber. (38-11)

active site (sīt) The area of an enzyme molecule to which a substrate bonds. (5-4)

adenine (ad'ə nin) One of the nitrogenous bases that compose nucleic acids; bonds only with thymine in DNA and only with uracil in RNA. (4-3)

adhesion (ad hē'zhən) The attraction between two unlike substances. (24-2)

adrenal (ə drē'nəl) **glands** Two endocrine glands, one on top of each kidney, that help regulate blood pressure and the concentration of various mineral salts in the blood. (36-5)

adrenocorticotrophic (a drē'nō kōr tə kō trof ik) **hormone (ACTH)** A hormone that is secreted by the anterior lobe of the pituitary gland and that stimulates the adrenal cortex to produce its hormones. (36-3)

aerobic (ār ō'bik) **respiration** Respiration that occurs in the presence of oxygen; a chemical reaction in which two molecules of pyruvic acid are broken down to 36 ATP's, carbon dioxide, and water. (5-16)

afferent neurons (af'ər ent nūr'ons) Nerve cells that carry impulses toward the spinal cord or the brain. (37-6)

agar (ä'gər) A gelatinlike culture medium obtained from seaweeds. (14-2)

agglutination (ə glü tə nā'shən) A severe antigen-antibody reaction in which red blood cells clump together. (9-10)

agglutinins (ə glü'tə nins) Antibodies that cause clumping of microbes. (17-5)

albinism (al'bə niz əm) Lacking melanin. (9-3)

algae (al'jē) Simple plantlike organisms that live in water and carry on photosynthesis. (14-1)

alleles (ə lēlz') The two or more related genes that control a trait. (8-10)

alveoli (al vē'ə lī) Small sacs at the ends of bronchioles; where exchange of gas takes place. (35-3)

alternation of generation A type of life cycle characterized by alternating asexually and sexually reproducing generations. (19-4)

altricial (al trish'əl) Pertaining to a category of birds that are born naked, blind, and completely helpless but with the instinctive ability to feed. (31-10)

amino (ə mē'nō) **acid** Organic compounds that are the building blocks of proteins. (3-21)

anaphase (an'ə fāz) The phase of mitosis and of meiosis during which the chromosomes move to opposite poles of a cell. (6-9)

anatomy (ə nat'ə mē) The study of the structure of organisms and their parts. (1-3)

anemia (ə nē'mē ə) A disease in which a shortage of red blood cells causes a shortage of oxygen in body cells. (26-14)

aneurysm (an'yə riz əm) A disorder that occurs when a weak spot in a main artery swells. (34-19)

angiosperms (an'je ə spērms) Flowering plants; the group of seed plants that produces seeds enclosed in fruit. (21-3)

annual (an'yü əl) **rings** Alternating rings of dark and light wood in stems and roots of woody plants; caused by summer and spring growth. (22-12)

anther (an'thər) The pollen-bearing portion of the stamen of a flowering plant. (21-8)

antheridium (an thə rid'ē əm) The male sex organ of a gametophyte plant; it produces the sperm cell. (19-5)

anthropologists (an thrə pol'ə jists) Specialists in the study of human ancestors. (11-1)

antibiotics (an tē bī ot'iks) Chemicals extracted from living microbes and used to kill or inhibit other microbes. (17-7)

antibody (an'tē bod ē) A specific protein produced by lymphocytes in blood, bone marrow, and several other body glands in response to a specific foreign substance called an antigen. (17-5)

anticoagulant (an tē kō ag'yə lənt) A chemical that prevents blood clotting. (26-14)

anticodon (an tē kō'don) A sequence of three bases on transfer RNA that combines with a specific codon of messenger RNA. (4-10)

antidiuretic (antī dī yū ret'ik) **hormone (ADH)** A hormone secreted from the posterior lobe of the pituitary gland; it helps the body conserve water by causing reabsorption of water in kidney tubules. (36-4)

antigen (an'tə jən) A substance, such as a protein or a polysaccharide, that stimulates the production of antibodies when it enters the bloodstream or tissue; viruses and bacteria are typical antigens. (9-9)

antitoxin (an tē tok'sin) An antibody that attaches itself to a toxin and makes the toxin harmless. (17-5)

anus (ā'nəs) The posterior opening of a digestive tract. (26-12)

aorta (ā ôr'tə) The largest artery in the human body. (34-13)

aphotic (ā fō'tik) **zone** The region of a marine habitat where light does not penetrate. (46-3)

apical dominance (ap'ə kəl dom'ə nəns) The inhibition of the growth of lateral branches in a plant by a hormone (auxin) produced in the terminal bud. (23-3)

apical (ap'ə kəl) **meristems** The growing regions of a plant, located near the tips of roots and shoots. (22-5)

aqueous (ā'kwē əs) **humor** A liquid that fills the anterior chamber of the eye. (37-18)

arachnids (ə rak'nids) A group of small arthropods, such as spiders, scorpions, ticks, and mites. (28-4)

archegonium (är kə gō'nē əm) The female sex organ of a gametophyte plant; it produces the egg cell. (19-5)

arteries (är'tər ēz) Blood vessels that carry blood away from the heart. (28-10)

arterioles (är tir'ē olz) Small branches and rebranches of arteries. (34-10)

arteriosclerosis (är tir ē ō sklə rō'sis) Hardening of the arteries; a disorder caused

by calcium deposit buildup along the walls of arteries, causing arteries to lose their elasticity. (34-18)

asters (as'tərz) The filaments that radiate from the centriole during cell division. (6-7)

asthma (az'mə) An allergic reaction of the bronchioles to pollen, mold spores, or other tiny particles in the air; characterized by attacks of wheezing, coughing, and hard breathing. (36-5)

atherosclerosis (ath ə ō sklə rō'sis) A disorder caused by a buildup of fatty material inside the arteries. (34-19)

atomic (ə tom'ik) **number** The total number of protons in the nucleus of an atom. (3-4)

atrium (ā'trē əm) One of the two upper chambers of the heart that receives venous blood. (29-12)

auricle (ôr'ə kəl) An earlike structure that contains receptors capable of detecting chemicals in water. (26-2)

autosomes (ô'tə sōmz) Any chromosomes other than sex chromosomes. (8-18)

auxins (ôk'sinz) Plant growth hormones. (23-2)

axon (ak'son) The branch of a nerve cell that carries impulses away from the cell body. (37-2)

bacilli (bə sil'ī) Bacteria shaped like rods or cylinders. (14-3)

bacteriology (bak tir ē ol'ə jē) The study of bacteria. (14-2)

bacteriophage (bak tir'ē ə fāj) A virus that infects bacteria; it is also called phage. (13-2)

bark (bärk) The total of all the tissues that are outside the vascular cambium of a woody stem. (22-11)

benthos (ben'thos) Organisms that live on the bottom or in the bottom sediments of a freshwater habitat. (45-3)

bilateral symmetry (bī'lat əɹ əl sim'ə trē) Two parts similar to each other to the right and left of a central axis. (25-3)

bile (bīl) A secretion of the liver that emulsifies ingested foods. (33-11)

biology (bī ol'ə jē) The science of life and life processes. (1-1)

bioluminescence (bī ō lū mə nes'əns) The ability of living organisms to produce light. (15-7)

biomes (bī'ōmz) All the plants and animals of a terrestrial community in a particular climate; most biomes are named for their climax vegetation. (47-3)

biosphere (bī'ə sfir) The entire living portion of the earth. (1-7)

biota (bī ō'tə) All the populations in a community. (41-6)

bone (bōn) A tissue composed of cells in a nonliving matrix. (38-1)

botany (bot'ə nē) The study of plants. (1-2)

Bowman's capsule Cuplike structure surrounding the glomerulus in a nephron. (35-8)

brackish water (brak'ish) A mixture of fresh water and seawater. (46-7)

bronchi (brong'kī) The tubes through which air flows from the trachea to the lungs. (35-3)

bronchioles (brong'kē olz) The smaller branching tubes of the bronchi. (35-3)

budding (bud'ing) A type of asexual reproduction in which a small extension, or bud, begins to grow directly from the body of the parent organism and later separates, developing into a new organism. (25-11)

cambium (kam'bē əm) The growing tissue in plants that produces xylem and phloem. (22-9)

capillaries (kap'ə ler ēz) The tiniest blood vessels; their walls are composed of a single layer of cells. (26-20)

capsid (kap'sid) The protein shell or jacket that encloses the nucleic acid of a virus. (13-3)

capsomers (kap'so mərs) The units of protein that form the capsid of a virus. (13-3)

capsule (kap'səl) The jellylike, nonliving layer outside the cell wall of bacteria. (14-3)

carbohydrates Organic compounds composed of a chain of carbon atoms with hydrogen and oxygen atoms attached; used for energy sources in organisms. (33-19)

carcinogens (kar sin'ə jens) Cancer causing substances. (40-23)

caries (kār'ēz) Tooth decay. (33-3)

carnivore (kār'nə vôr) A meat-eating organism. (42-3)

carpel (kār'pəl) The innermost ring of flower parts; it functions as the female reproductive organ of a flowering plant. (21-8)

cartilage (kār'tə lij) A noncellular bone-like tissue that is composed of tough bands of flexible protein (collagen fiber) and is blue-white in color; in the adult skeleton, cartilage is found in areas where bones come together and in the nose and the ears. (38-2)

catalyst (kat'ə list) A substance that speeds up a chemical reaction without itself being chemically changed. (5-3)

cell (sel) The smallest living unit or organism. (1-4)

cell wall (sel wôl) The nonliving, cellulose structure that surrounds the plasma

membrane of plant cells. (2-9)

cellulose (sel'yə lōs) The main structural material of plant cell walls. (3-16)

cerebellum (ser ə bel'am) The round and wrinkled region of the vertebrate brain between the brainstem and the cerebrum; its main function is to coordinate smooth skeletal movements. (37-10)

cerebrum (ser'ə brəm) The part of the vertebrate brain that receives sensory stimuli; it controls voluntary functions and higher mental activity. (37-10)

cervix (sér'viks) The opening of the uterus. (39-12)

chaparral (chap ə ral') A terrestrial region that receives good winter rainfall but little rain during the summer; evergreen trees and shrubs with thick leaves are found in this biome. (47-11)

chemical (kem'ə kəl) **bond** A force that holds atoms together. (3-8)

chemotrophic (ke mo trof'ik) **bacteria** Bacteria that oxidize compounds of iron, sulfur, nitrogen, or other mineral substances to obtain energy. (14-4)

chitin (kī'tin) A tough lightweight material found in the exoskeleton of insects and other arthropods. (28-3)

chlorophyll (klôr'ə fil) The green pigment in plants that is essential to converting light energy to food. (2-7)

chloroplast (klôr'ə plast) A plastid containing chlorophyll. (2-7)

chromatid (krō'mə tid) One strand in a double-stranded chromosome after replication. (6-7)

chromatin (krō'mə tin) The compact mass of very small fibers that become chromosomes during cell division. (2-6)

chromatophore (krō'mə tə fôr) A specialized cell that contains one or more pigments. (29-11)

chromosomes (krō'mə sōmz) Rod-shaped nuclear bodies that contain genetic material. (2-6)

chromosome theory All genes are carried on chromosomes and are distributed equally during mitosis. (8-15)

chyme (kīm) The pasty mixture that results from a mixture of food and gastric juices. (33-7)

cilia (sil'ē ə) Hairlike structures that often cover the entire surface of a cell; used for locomotion. (15-4)

cocci (kok'sī) Sphere-shaped cells. (14-3)

codon (kō'don) A sequence of three bases on messenger RNA that code a specific amino acid. (4-6)

cohesion (kō hē'zhən) The clinging together of like molecules. (3-8, 24-2)

colon (kō'lən) The large intestine. (33-16)

colony (kol'ə nē) A group of similar living cells that cling together. (14-1)

colostrum (kə los'trəm) A special type of milk that contains many antibodies and is produced during the first few days an infant is nursed. (17-6)

commensalism (kə men'sə liz əm) One of the simplest symbiotic relationships in which organisms of one species benefit and those of another are unaffected. (42-8)

community (kə myü'nə tē) The level of organization that includes a group of populations living in an area. (1-6)

concentration gradient (kon sən trā'shən grā'dē ənt) The difference between a region of high concentration of a substance and a region of lower concentration. (7-2)

cones (kōnz) Highly modified cells of the eye; used for daylight vision and can detect color. (37-18)

conifers (kō'nə fərs) A group of woody plants that bear seeds in cones: pines, spruce, and so on. (47-5)

consumer (kən sü'mər) Any organism or population that obtains its food and energy directly or indirectly from a producer. (41-11)

conjugation (kon jə gā'shən) The type of sexual reproduction in protists that involves the exchange of nuclear material by temporarily fused cells. (15-4)

control (kən trol') In an experiment, the normal part used as a standard for comparing the results. (1-10)

cork (kôrk) The layer of tissue near the outside of the stem in woody plants; it prevents excessive loss of water. (22-11)

cornea (kôr'nē ə) The outer part of the sclera; it is transparent and admits light into the eye. (37-18)

corpus luteum (kôr'pəs lü'tē əm) The yellowish body that results when the follicle heals after ovulation; it secretes progesterone. (39-6)

cortisol (kôr'tə söl) A hormone secreted by the adrenal cortex. (36-6)

cotyledon (kot ə lē'dən) The seed leaf in a plant embryo; it is a reservoir of food for the germinating plant. (21-11)

covalent (kō vā'lənt) **bond** The sharing of electrons between atoms. (3-8)

cristae (kris'tē) The shelflike or infolded structures in mitochondria. (2-13)

culture (kul'chər) A group of microscopic organisms grown artificially in the laboratory. (14-2)

culture medium A liquid or moist solid that provides cultured organisms with food; agar is a culture medium. (14-2)

cytokinesis (sī tō ki nē'sis) Division of the cytoplasm and its contents. (6-5)

cytokinins (sī tō ki'nins) A group of hormones that stimulate cell division in plants. (23-7)

cytoplasm (sī'tə plaz əm) The clear, gelatinlike material outside the nucleus and inside the plasma membrane. (2-7)

cytosine (sit'tə sin) One of the nitrogenous bases that compose nucleic acids; bonds only with guanine. (4-3)

daughter (dô'tər) **cells** Newly formed cells, having identical nuclear material, that result from the mitosis of a previously existing cell.

deciduous (di sij'ù əs) **forest** A forest where most of the trees lose their leaves in the fall. (47-7)

decomposer (dē kəm pō'zər) Any bacterium or mold that can recycle dead matter into organic nutrients. (41-12)

deforestation (dē fôr ə sta'shən) The process by which trees or forest are cut down without being replaced. (48-4)

dehydration (dē hī drā'shən) **synthesis** A chemical reaction in which small molecules combine to form larger molecules by the removal of water. (3-15)

dendrite (den'drīt) The branched structure of a nerve cell that carries impulses toward the cell body. (37-2)

denitrification (dē nī trə fə kā'shən) The breakdown of nitrogen compounds by certain bacteria, resulting in the return of nitrogen to the atmosphere. (43-5)

deoxyribonucleic (dē ok sə rī bō nü klé'ik) **acid (DNA)** A double helix of repeating units of deoxyribose sugar, phosphates, and nitrogen bases; the genetic component that specifies the exact sequence of amino acids in proteins. (4-1)

desertification (dez ər tif ə ka'shən) The process by which a grassland loses its root system and disintegrates to become a desert. (47-8)

diabetes mellitus (dī ə bē'tis mel'ə təs) The disease caused by hyposecretion of insulin from the islets of Langerhans. (36-9)

diaphragm (di'ə fram) The sheet of muscles that separates the thoracic and abdominal cavities in mammals. (35-4)

dicotyledons (dī kot ə lē'dəns) The group of flowering plants that have two cotyledons in their seeds. (21-13)

diffusion (di fyū'zhən) The process by which molecular collisions cause a substance to move down a concentration gradient. (7-3)

digestion (də jes'chən) The physical and chemical breakdown of food into the molecular form that can be absorbed into the bloodstream and used by cells. (33-1)

dihybrid (dī hī'brid) Individuals that are heterozygous for two traits. (8-12)

diploid (dip'loid) Having two complete sets of chromosomes. (6-15)

disaccharide (dī sak'ər id) A carbohydrate composed of two simple sugars. (3-15)

dominant (dom'ə nənt) **trait** The genetic trait that appears as a phenotypic expression in a hybrid. (8-4)

dormancy (dôr'mən sē) The state of an organism in which life processes have slowed down or completely stopped. (21-2)

duodenum (dū ə dē'nəm) The first section of the intestines, leading directly from the stomach. (33-8)

ecology (ē kol'ə jē) The study of the relationship of organisms to their environment. (1-6)

ecosphere (ē'kə sfir) The entire living portion of the earth and its physical environment. (1-7)

ecosystem (ē'kə sis təm) The interaction of the community with its physical environment. (1-6)

ectoderm (ek'tə derm) The outermost layer of cells in an embryo. (26-1)

efferent neurons (ef'ər ənt nūr'ons) Nerve cells that carry impulses away from the spinal cord or brain. (37-6)

electron (i lek'tron) A negatively charged particle in orbit around the nucleus of an atom. (3-3)

element (el'ə mənt) Matter entirely composed of atoms with the same atomic number. (3-4)

embryo (em'brē ō) An undeveloped organism before hatching, birth, or germination. (39-6)

emphysema (em fə sē'mə) A disorder of the respiratory system caused by aging and smoking; the small bronchioles leading to the alveoli become plugged and the alveoli break down and eventually disappear, making exchange of gases progressively more difficult. (35-5)

endemic (en dem'ik) Describing disease that is always present among a population. (17-1)

endoderm (en'dō dērm) The innermost layer of cells in an embryo. (26-1)

endoplasmic reticulum (en dō plaz'mik ri tik'yə ləm) The network of canals that extend throughout the cytoplasm from the plasma membrane to the nucleus. (2-12)

endosperm (en'dō spērm) The portion of a seed that is a collection of stored food for the embryo. (21-2)

entomology (en tə mol'ə jē) The branch of zoology that studies insects. (28-12)

enzyme (en'zīm) A protein that acts as a biochemical catalyst. (5-3)

epicotyl (ep ə kot'al) The region of the plant embryo, above the cotyledons, that will develop into the shoot of the plant. (22-3)

epidemic (ep ə dem'ik) A disease that spreads rapidly through a population. (17-1)

epidermis (ep ə der'mis) The outermost layer of cells. (20-2)

epiglottis (ep ə glot'is) A flap of tissue that covers the opening between the vocal cords, preventing food from entering the windpipe during ingestion of food. (33-4)

epinephrine (ep ə nef'rin) Adrenalin; the main hormone of the adrenal medulla. (36-5)

epiphytes (ep'ə fitz) Plants that grow on other plants, such as trees, but are non-parasitic. (19-3)

erythrocytes (i rith'rō sīts) Red blood cells. (34-3)

esophagus (ē sof'ə gəs) The tube that conducts food from the pharynx to the stomach. (26-18)

estrogen (es'trə jən) A hormone produced by ovaries; it stimulates the expression of primary and secondary female characteristics. (39-4)

estuary (es'chü er ē) A semienclosed coastal body of water. (46-7)

eucaryotic (yü'kar ē o tik) **cell** A cell with a true nucleus as well as other membrane-bound organelles. (2-19)

euphotic (yü fō'tik) **zone** The top zone of a marine habitat that is penetrable by light. (46-3)

eutrophication (yü trə fə ka'shən) Premature aging and death of a lake that slowly becomes shallow by the accumulation of dead plant material. (43-9)

Eustachian (yü stā'kē ən) **tube** A tube in the ear that allows the air pressure in the middle ear to remain equal to that on the outside of the tympanic membrane. (37-19)

evolution (ev ə lü'shən) The process by which populations change and develop adaptations. (10-7)

excretion (ek skrē'shən) The process of eliminating waste. (26-4)

exocytosis (ek sō sī tō'sis) The process by which cells export materials in vacuoles across the plasma membrane. (7-11)

exoskeleton (ek sō skel'ə tən) A skeleton that covers the outside of the body, like a suit of armor. (28-3)

expiration (eks pə rā'shən) The muscular activity involved when the diaphragm is pushed upward, forcing air out of the lungs. (35-4)

extinct (ek stingkt') Without a living member of a species; death of a population. (1-5)

fact (fakt) A true statement that can always be proved. (1-12)

facultative (fak'al tā tiv) **anaerobes** Bacteria that grow with or without oxygen. (14-4)

Fallopian (fo lō'pēən) **tube** The tube through which an ovum is transported from the ovary to the uterus; oviduct. (39-5)

fat (fat) An organic compound composed of fatty acids and glycerol. (3-18)

feces (fē'sēz) Waste matter excreted from a digestive tract. (26-8)

fermentation (fēr men tā'shən) The conversion of sugar to alcohol and other substances; anaerobic respiration. (14-2)

fetus (fē'təs) A mammalian embryo about eight weeks old that has all internal organs in some stage of development and bones beginning to take form. (39-11)

fibroblasts (fi'brə blasts) Cells that secrete collagen fiber that is the main constituent of connective tissue. (38-3)

filament (fil'ə mənt) The stalk of the stamen, which supports the anther. (21-8)

fibrin (fi'brən) An insoluble protein that forms tough threads that trap red blood cells and form a clot. (34-6)

flagella (flə jel'lə) Threadlike structures that propel cells through liquids. (14-1)

follicle (fol'ə kəl) A fluid-filled area of an ovary, in which an egg develops. (39-3)

follicle-stimulating hormone (FSH)
A hormone from the anterior lobe of the pituitary gland that stimulates the development of the tubules in the testes and the manufacture of sperm. (39-2)

foramen magnum (fə rā'men mag'nəm)
The opening where the spinal cord enters the base of the skull. (11-2)

gall bladder (gôl blad'er) The container in vertebrates that stores bile. (33-11)

gamete (gam'ēt) A reproductive cell having one set of chromosomes. (6-12)

gametophyte (gə mē'tə fit) **generation**
The generation of plants that produces gametes. (19-4)

gasohol (gas'ə hōl) A mixture of gasoline and alcohol. (18-5)

gastrovascular cavity (gas trō vas'kyə lər kav'ə tē)
The central cavity of coelenterates. (25-15)

gene (jēn) A sequence of nucleotides in a chromosome; the unit that transmits hereditary traits. (4-14)

genetics (jə net'iks) The study of genes and how they interact with each other in the development of new organisms. (8-1)

genotype (jen'ə tīp) The actual alleles possessed by an individual; the genetic content of an organism. (8-10)

genus (jē'nəs) The category of organisms just above the species; the first name in the scientific name of an organism. (12-4)

geotropism (jē ot'rə piz əm) The growth response of plant roots to gravity. (23-8)

germinate (jēr'mə nāt) To begin growing; to sprout. (21-5)

germination (jēr mə nā'shən) The beginning development of the plant embryo after a period of dormancy. (22-4)

gestation (jes tā'shən) **period**
In live-born organisms, the period of time from fertilization to birth. (32-19)

gibberellins (jib ə rel'inz) Plant hormones that stimulate growth, causing increased cell division and cell elongation. (23-6)

gill slits (gil slitz) Openings in the pharynx that extend through the body wall and to the outside environment; present in many chordates during early embryonic development. (29-1)

gizzard (giz'erɪd) A muscular digestive structure in earthworms and birds that grinds food with the help of ingested sand and other abrasive materials. (26-18)

glomerulus (glə mer'ù ləs) A tuft of capillaries in a nephron. (35-8)

glucagon (glü'kə gon) A hormone from the islets of Langerhans that has the opposite effect of insulin; causes glycogen to be converted to glucose and sent into the bloodstream. (36-9)

glycogen (glī'kə jən) A carbohydrate that is the storage form of glucose in animal cells. (3-16)

glycolysis (glī kol'ə sis) A series of chemical reactions that breaks the 6-carbon glucose molecule into two 3-carbon molecules of pyruvic acid; also called anaerobic respiration. (5-15)

goiter (goi'tər) Abnormal enlargement of the thyroid gland caused by iodine deficiency. (36-7)

Golgi apparatus (gol'jē əp ə rā'təs) The group of membranes that look like a stack of flattened balloons and act as the main part of the cell's exporting machinery. (2-12)

gonorrhea (gon ə rē'ə) A venereal disease caused by a bacterium informally known as

the gonococcus; usual signs of the disease are a burning sensation and a puslike discharge from the genital organ. (17-2)

gram-negative bacteria Bacteria that are not colored by Gram stain. (14-2)

gram-positive bacteria Bacteria that accept and are colored by Gram stain. (14-2)

grana (grā'nə) Stacks of disklike plates in the chloroplast. (5-8)

gray matter Interneuron cell bodies that make up the cerebral cortex and the interior of the spinal cord. (37-7)

guanine (gwä'nēn) One of the nitrogenous bases that compose nucleic acids, bonds only with cytosine. (4-3)

guard (gärd) **cells** The crescent-shaped cells that enclose and control the size of leaf pores through which water evaporates and gases are exchanged. (22-8)

guttation (gu tā'shən) The forcing of water out through the tips and edges of leaves, caused by increased osmotic pressure in the roots. (24-8)

gymnosperms (jim'nə spērms) The group of seed plants that produces naked seeds, or seeds that are not enclosed within a fruit. (21-3)

habitat (hab'ə tat) The physical environment in which an organism naturally lives and grows. (25-12)

haploid (hap'loid) Having only one set of chromosomes. (19-5)

hemoglobin (hē mə glo'bən) The oxygen-carrying molecule in red blood cells. (9-4)

hemolytic (hē mə lit'ik) Able to break down red blood cells and small blood vessels. (30-6)

herbicide (hēr'bə sīd) A chemical that kills plants. (23-4)

herbivore (hēr'bə vôr) A plant-eating organism. (42-3)

hermaphrodite (hēr maf'rə dīt) An animal that has functioning male and female reproductive organs. (25-19)

heterocysts (het'ər ə sists) In the filament of some blue-green algae, weak points where the filament can break. (14-7)

heterotrophic (het ə r ə trof'ik) **bacteria** Bacteria that cannot make their own food; dependent on organic materials that have been made by other organisms. (14-4)

heterozygous (het ə r ə zī'gəs) Having unlike alleles. (8-12)

holozoic (hol ə zō'ik) An organism that eats solid particles for food. (15-1)

homeostasis (hō mē ə stā'sis) A stable condition in the internal environment of the body. (35-6)

homologous (hō mol'ə gəs) **chromosome** A pair of chromosomes identical in form and gene arrangement. (6-13)

homozygous (hō mə zī'gəs) Having like alleles. (8-12)

hormones (hôr'mōnz) A chemical secretion that controls and coordinates cell and organ functions. (23-1)

human chorionic (kôr ē on'ik) **gonadotrophin** (gon ə də trof'in) (**HCG**) A hormone that retards the degeneration of the corpus luteum for about three months so that the corpus luteum produces progesterone until the placenta takes over progesterone production. (39-11)

hydrolysis (hī drol'ə sis) The chemical breakdown of a substance by combination with water. (3-5)

hyperglycemia (hī pār gli sē'mē ə) A high blood sugar level stimulated by a hyposecretion of insulin. (36-9)

hyphae (hī'fē) Branching filaments. (16-4)

hypocotyl (hī pə kot'əl) The region of the plant embryo between the radicle and the epicotyl. (22-3)

hypoglycemia (hī pō gli sē'mē ə) A low blood sugar level caused by secretion of excess insulin. (36-9)

hypothalamus (hi pə thal'ə mäs) In humans, the region of the brain that controls such body functions as thirst, pleasure, pain, anger, sexual drive, and secretion of pituitary hormones. (37-14)

hypothesis (hī poth'ə sis) A temporary explanation of observed or experimental results. (1-12)

icosahedron (ī kō sə hē'drən) A solid geometric figure having 20 surfaces; the capsid of many viruses that take this form. (13-3)

immunity (i myü'nə tē) The resistance of one organism to an invading organism or antigen. (15-5)

inorganic (in ôr gan'ik) **compounds** Compounds that do not contain the element carbon. (3-13)

inspiration (in spə ra'shən) The muscular activity involved when the diaphragm drops into the abdomen, creating decreased air pressure in the thorax and causing air to rush into the lungs. (35-4)

insulin (in'sə lin) A hormone, produced in the islets of Langerhans, that helps regulate the quantity of sugar in the blood; functions to decrease the blood sugar and cause it to be stored as glycogen. (36-9)

interferon (in tər fir'on) A protein that protects animal cells against infectious viruses. (13-8)

interphase (in'tər fāz) The period of growth between cell divisions. (6-2)

interstitial (in tər stish'al) **cell-stimulating hormone (ISCH)** A hormone from the anterior lobe of the pituitary

gland that stimulates the nontubule cells of the testes (called interstitial cells) to produce male hormones. (39-2)

intertidal (in tər tī'dəl) **zone** The region in a marine habitat where the tides ebb and flow. (46-3)

invertebrate (in vēr'tə brit) An animal without a backbone. (25-5)

ion (ī'ən) An atom with an unequal number of electrons and protons; a charged atom. (3-7)

ionic (ī on'ik) **bond** The attraction between ions of unlike charge. (3-8)

iris (ī'ris) The colored portion of the eye, behind the cornea and surrounding the pupil, that regulates the amount of light entering the eye. (37-18)

islets (ī'lets) **of Langerhans** (läng'ər häns) The small, round specialized tissue of the pancreas that produces insulin. (36-9)

isotopes (ī'sə tōpz) Atoms of the same element differing only in mass number. (3-6)

Jacobson's organ A specialized organ containing nerve endings that are sensitive to taste and smell, located in the roof of a snake's mouth. (30-4)

kidneys The bean-shaped organs that lie, in humans, on each side of the spine in back of the abdomen; the main function is to filter wastes and surplus materials from the blood and to put these wastes into a form that can be excreted from the body. (35-7)

kilojoule The amount of energy which, when added to 1 kg of water, will raise the temperature of the water by 4.2°C. (33-19)

kinetochore (ki nē'tə kôr) The darkened area on a chromosome where the chromatids are attached. (6-7)

kingdom In biological taxonomy, the highest category in a hierarchy that includes all organisms. (12-4)

lactation (lak tā'shən) Producing milk. (39-13)

larynx (lar'ingks) The voice box, located between the pharynx and the trachea in the human respiratory system. (33-4)

legumes (leg'yūmz) Any plant of a large widely-distributed family of plants including peas, beans, alfalfa, and soybeans. (43-5)

lentic (len'tik) **habitat** The one of two freshwater habitats that refers to standing water, including all kinds of lakes. (45-1)

lenticels (len'tə sels) Pores in the cork of woody plants, through which gases are exchanged. (22-11)

lichen (lī'kən) The symbiotic community of certain algae and fungi, classified as one species. (42-10)

ligaments (lig'ə ments) The dense parallel bundles of collagen fibers that hold bones together at a joint. (38-3)

limnetic (lim net'ik) **zone** The open-water zone that extends downward to a depth where there is enough light for good photosynthetic activity. (45-4)

littoral (lit'ər əl) **zone** The shallow-water region where light penetrates all the way to the bottom. (45-4)

lotic (lō'tik) **habitat** The one of two freshwater habitats that refers to running water, including rivers, streams, brooks, creeks, springs, or other water habitats with currents. (45-1)

luteinizing (lū'tē ə nīz ēng) **hormone (LH)** The hormone that, in females, stimulates follicle development and the production of estrogen and progesterone by the ovaries. (39-4)

lysin (lī'sin) An antibody that causes the cell walls of bacteria to break open. (17-5)

lysis (lī'sis) The bursting open of bacteria after replication of an invading virus. (13-6)

lysosomes (lī'sə sōmz) In a cell, spherical bodies that contain potent protein digestive enzymes. (2-15)

macronucleus (mak rō nū'klē əs) The large nucleus in Paramecium and other protozoans that regulates the day-to-day nutritional activities of the cell. (15-4)

malnutrition (mal nū trish'ən) The condition that results when one or more essential foods are missing from the diet. (33-14)

mantle (man'təl) A fold of tissue that covers the dorsal surface of a mollusk; its main function is to secrete a limestone shell. (27-1)

mariculture (mar'ə kul chər) Marine farming; mariculture techniques can increase production of oysters, clams, and fish. (46-8)

mass (mas) **number** The total number of protons and neutrons in the nucleus of an atom. (3-5)

mechanoreceptors (mek ə nō ri sep'tərs) Sensory nerve endings that detect vibrations and respond by bending or stretching. (37-15)

medulla (mi dul'ə) The main region of the brainstem at the base of the brain; it controls the activity of vital internal organs, including respiration and heart beat. (37-11)

meiosis (mī ō'sis) Eucaryotic cell division that distributes one set of two complete sets of chromosomes to resulting cells. (6-12)

melanin (mel'ə nin) The pigment that colors human skin, hair, and the iris of the eye. (9-3)

menstrual (men'strū əl) **cycle** The regular sequence of changes that takes place in the mature female reproductive system when fertilization does not occur. (39-5)

mesoderm (mes'ə dərm) The middle layer of cells in an embryo. (26-1)

metamorphosis (met ə mōr'fə sis) A series of changes in form in the development

of an animal as it matures. (28–13)

metaphase (met'ə fāz) [in meiosis] The state in which the crossing-over of portions of homologous pairs of chromosomes is completed. (6–13)

metaphase [in mitosis] The stage in which the chromosomes become aligned along the equator of the cell and the chromatids finally separate. (6–8)

microbiology (mī krō bī ol'ə jē) The study of microorganisms. (1–2)

micronucleus (mī krō nü'kle əs) The small nucleus of *Paramecium* and other protozoans that is active during reproduction. (15–4)

microorganism (mī krō ôr'gə niz əm) A small organism that is visible only through a microscope; microbe. (1–2)

microvilli (mī'krō vil ī) The microscopic cells that line the surface of villi in the small intestine. (33–10)

mitochondria (mī tə kon'drē ə) In the cytoplasm of a cell, round or rod-shaped bodies in which most of the energy-releasing chemical reactions occur; the “powerhouse” of the cell. (2–13)

mitosis (mī tō'sis) Eucaryotic cell division that distributes two complete sets of chromosomes to resulting cells. (6–1)

molecule (mol'ə kyül) Any distinct group of atoms held together by a chemical bond. (3–1)

molt (mōlt) To shed feathers, skin, shell, and hair before a new growth. (31–3)

monerans (mo nē'rans) Members of the kingdom Monera, characteristically unicellular with no organized nucleus and reproducing mostly by asexual cell division. (14–1)

monocotyledons (mon'ə kot'ə lē'dəns) The group of flowering plants that have one cotyledon in their seeds. (21–13)

monoploid (mon'ə ploid) Having one set of chromosomes. (6–15)

monosaccharide (mon ə sak'ə rīd) A single sugar; the basic component of carbohydrates. (3–14)

mortality (môr tal'ə tē) The rate of death within a population. (41–4)

mucus (myü'kəs) A slimy glandular secretion that lubricates membranes and helps filter particles such as dust and bacteria out of the air. (33–8)

mutagen (myü'tə jen) Any one of many agents that may alter one or more levels of the genetic material. (4–15)

mutation (myü ta'shən) Any permanent change in one or more inherited genes of an organism. (4–15)

mutualism (myü'chü ə liz əm) The most dependent symbiotic relationship in which each party depends completely upon the other for its survival. (42–10)

mycelium (mī sē'lē əm) The mass of hyphae that form the body of a fungus. (16–4)

myofibrils (mī ə fī'brəls) Bundles of fine threadlike fibers that form a muscle fiber. (38–11)

myosin (mī'ə sin) The thicker bundles of filaments that together with actin compose the myofibrils in muscle fiber. (38–11)

natality (nā tal'ə tē) The birthrate within a population. (41–4)

nekton (nek'ton) The ecological category of organism that includes fishes, amphibians, turtles, and a variety of insects that are good swimmers. (45–3)

nephridia (ni frid'ē ə) Excretory units of the kidneys. (26–21)

neritic (ni rit'ik) **zone** In a marine habitat, the shallow-water region over the continental shelf. (46-3)

nerve (nerv) A group or bundle of neurons. (37-2)

neuron (nür'on) A specialized cell that is capable of receiving stimuli and transferring those stimuli for response; also called a nerve cell. (37-2)

neurotoxin (nür ò tok'sin) A poison that acts upon the nervous system, causing paralysis. (30-6)

neuston (nüs'tən) Organisms that rest or swim on the surface of a freshwater habitat. (45-3)

neutron (nü'tron) An electrically neutral particle in the nucleus of an atom. (3-5)

niche (nich) A population's complete role in an ecosystem. (41-9)

nitrogen fixation (nī'trə jən fik sās'hən) The conversion of atmospheric nitrogen into ammonia (NH₃) or usable nitrates; accomplished largely by bacteria. (14-4)

norepinephrine (nôr ep ə nef'rin) A hormone secreted by the adrenal medulla; it is a powerful constrictor of arterioles; it supplements the effect of epinephrine. (36-5)

nucleocapsid (nü klē ə kap'sid) The nucleic acid and the capsid of a virus. (13-3)

nucleolus (nü klē'ə ləs) A small spherical body within the nucleus of a cell except during cell division. (2-6)

nucleotide (nü'klē ə tīd) A repeating subunit of nucleic acids, composed of a phosphate, a deoxyribose, and a nitrogen base bonded together. (4-3)

nucleus (nü'klē əs) The organelle that contains chromosomes and is the control center of the cell; the central mass of an atom. (2-6, 3-3)

obligate aerobes (ob'lə gāt ār'ōbz) Bacteria that must have oxygen. (14-4)

obligate anaerobes (ob'lə gāt an ār'ōbz) Bacteria that grow only in the absence of oxygen. (14-4)

ocean current In an ocean, a type of water circulation that is like a river. (46-1)

oceanic (ō shē an'ik) **zone** The region of a marine habitat beyond the neritic zone. (46-3).

olfactory (ol fak'tər ē) **nerves** Chemoreceptors with endings in the mucous membrane of the nasal cavity; chemicals in the air strike the nerve endings and trigger impulses that travel through the olfactory nerves. (37-17)

omnivore (om'nə vôr) An organism that feeds on both plant and animal substances. (32-8)

oncogenic (ong kə jen'ik) Capable of causing cancer. (13-7)

operculum (ō pēr'kyə ləm) The hard structure that covers the gills of bony fishes. (29-6)

oral groove (ôr'al grüv) A deep cavity along one side of *Paramecium* and certain other protozoans. (15-4)

organ (ôr'gən) A group of tissues that perform one or more specific functions. (1-4)

organelle (ôr gə nel') Specialized cell parts contained in the cytoplasm. (2-6)

organic compounds (ôr gan'ik kom'pounds) Compounds that contain the element carbon. (3-13)

organism (ôr'gə niz əm) An individual living thing. (1-2)

osmosis (oz mō'sis) The diffusion of water or any other solvent through a selectively permeable membrane. (7-5, 24-6)

osteocytes (os'tē ə sītz) Bone cells. (38-1)

ovary (ō'vər ē) A female reproductive organ found in both plants and animals. (39-3)

ovipositor (ō və poz'ə tər) A long, hollow tube that some female insects use to bury eggs. (28-13)

ovum (ō'vəm) Egg; female gamete. (39-3)

oxytocin (ok si tō'sin) The hormone that stimulates the release of milk when the breast is suckled by a baby. (39-13)

pancreas (pan'krē əs) A gland that lies behind and slightly below the stomach; it produces digestive enzymes and the hormone insulin. (33-11)

pandemic (pan dem'ik) Describing an epidemic disease that spreads through a whole nation or the world. (17-1)

parasite (par'ə sīt) An organism living in or on another organism (host) at the expense of the host organism. (26-1)

parasympathetic nerves (par ə sim pə thet'ik) In the autonomic nervous system, the peripheral nerves that aid in maintaining homeostasis within internal organs, such as the heart and the glands. (37-9)

pasteurization (pas chər ə zā'shən) Heating and then rapid cooling of a liquid to kill bacteria. (14-2)

pathogenic (path ə jen'ik) Capable of causing disease. (13-2)

pelagic (pə laj'ik) All life in the open water, including all the plankton, nekton, and neuston. (46-2)

pellicle (pel'ə kəl) The thickened outer layer of the plasma membrane; helps flagellates maintain their shape. (15-3)

pelvic girdle (pel'vik) A solid structure made of three bones fused together: the ilium, the ischium, and the pubic bone; in humans, supports the muscles and bone of the upper leg. (38-7)

penis (pē'nis) In male mammals, the organ through which urine or sperm leave the body; the male reproductive organ. (39-1)

peptide (pep'tīd) A short chain of amino acids (less than 50 amino acids). (33-7)

peptide bond The chemical bond that links amino acids together; the covalent bond between the amino group of one amino acid and the acid group of another amino acid. (3-22)

pericardium (pər ə kar'de əm) A saclike membrane that encloses the heart. (34-7)

periphyton (pə rif'ē ton) Organisms that are attached to rooted plants or objects sticking up from the bottom of a freshwater habitat. (45-3)

peristaltic waves (per ə stal'tik) Waves of regular muscular contractions in the walls of the digestive tract that move the food along. (33-5)

permafrost (pər'mə frōst) A layer of soil that remains permanently frozen. (47-4)

petri dish (pā'trē) A flat glass dish with a matching cover used for growing cultures in bacteriology. (14-2)

phage (fāj) A virus that infects bacteria; it is also called a bacteriophage. (13-2)

phagocytosis (fag ə sī tō'sis) The process by which cells take in solid objects. (7-10)

pharynx (fär'ingks) The cavity or muscular tube that connects the mouth and nasal passage with the esophagus. (26-3)

phenotype (fē'nə tīp) The physical appearance of an individual; the physical result of having a certain pair of alleles. (8-10)

phloem (flō'em) The vascular tissue in plants that conducts food down from the leaves. (22-7)

photoperiodism (fō tō pir'ē ə diz əm) The response of plants to varying exposures to light and darkness. Flowering is one response. (23-9)

photophosphorylation (fō tō fos fər ə lā'shən) The process by which light energy links a phosphate group to ADP to form ATP. (5-6)

photoreceptors (fō tō ri sep'tərs) Cells, tissues, or organs that are capable of transforming light into sensory nerve impulses. (26-2)

phototropic (fō tō trop'ik) **bacteria** Bacteria capable of using light energy to make food. (14-4)

phototropism (fō tōt'rə piz əm) The response (bending) of a plant to light. (23-2)

phylum (fī'ləm) The category of organisms just below the highest category, the kingdom. (12-4)

physiology (fiz ē ol'ə jē) The study of the functions of organisms. (1-3)

phytoplankton (fī tō plangk'tən) Plant-like plankton; food producers (mostly algae) that carry on photosynthesis and are the beginning of grazing food chains in fresh water. (45-3)

pinocytosis (pi nō sī tō'sis) The process that enables a cell to take in materials in liquid solution. (7-10)

pituitary (pi tū'ə ter ē) **gland** The "master gland" located at the bottom of the brain and just above the roof of the mouth; one of its major functions is to regulate growth. (36-2)

placenta (plə sen'tə) A large thin membrane in the uterus across which food and wastes are exchanged between mother and embryo by means of the umbilical cord. (39-9)

plankton (plangk'tən) Small aquatic organisms that either cannot swim or swim poorly near the surface of a body of water and serve as food for larger organisms. (28-11)

plaque (plak) A clear area in a bacterial culture where a phage has destroyed all the

bacteria. (13-6)

plasma (plaz'mə) The liquid part of the blood; yellow-brown in color and composing about 55 percent of the blood. (34-2)

plasma membrane (plaz'mə mem'brān) A very thin, selectively permeable tissue that surrounds the cytoplasm. (2-8)

plasmolysis (plaz mol'ə sis) The shrinkage of cells, caused by the diffusion of water out of the cells. (24-7)

plastid (plas'tid) An organelle in the cytoplasm of plant cells; chloroplasts are the most common plastid. (2-7)

pleura (plūr'ə) The smooth, moist membrane that lines and lubricates the lungs and inner walls of the chest cavity. (35-3)

pollination (pol ə nā'shən) The process of transferring pollen from an anther to a stigma. (21-9)

polygenic (pol ē jen'ik) Involving several genes to produce a trait. (9-1)

polysaccharide (pol ē sak'ə rid) A large carbohydrate molecule composed of simple sugars bonded together. (3-16)

polysome (pol'ē sōm) A cluster of ribosomes attached to a strand of messenger RNA. (4-11)

population (pop yə la'shən) A group of organisms of one species defined by location and time. (41-1)

precocial (pri kō'shəl) Pertaining to a category of birds born with downy feathers and capable of running about within hours after hatching. (31-10)

primates (prī'mitz) Members of the order of mammals that includes humans, apes, monkeys, marmosets, and lemurs. (32-11)

procaryotic (pro'kar ē o tik) **cell** A cell that lacks a distinct nucleus and other membrane-bound organelles. (2-19)

producer (prə dü'sər) An organism or population that uses photosynthesis to transform light energy from the sun into food. (41-10)

profundal (prə fun'dəl) **zone** The water region where there is not enough light for a significant amount of photosynthesis to occur. (45-4)

proglottid (prō glot'id) A segment of a tapeworm's body. (26-10)

prolactin (prō lak'tin) The hormone that stimulates the cells in the breasts to produce milk. (39-13)

prophage (prō'fāj) Viral nucleic acid that acts as an extra set of genes on the bacterial chromosome. (13-6)

prophase (prō'fāz) [in meiosis] The stage in which homologous chromosomes migrate to the equator of a cell where crossing-over begins. (6-13)

prophase [in mitosis] The first phase of mitosis during which the nuclear membrane disappears and chromatin material condenses into doubled chromosomes. (6-6)

proteases (prō'tē ās ez) Protein-digesting enzymes. (33-13)

proteins (prō'tēns) Long chains of amino acids linked together by peptide bonds. (33-18)

protista (prō tis'tə) The kingdom that includes unicellular and eucaryotic organisms. (15-1)

protists (prō'tists) Organisms of the kingdom Protista. (15-1)

proton (prō'ton) A positively charged particle in the nucleus of an atom. (3-3)

protozoa (prō tə zō'ə) Animallike protists. (15-1)

pseudopodia (sü də pō'dē ə) False feet. (15-2)

psychosomatic (sī kō sō mat'ik) Disorders or diseases that people think themselves into; it means "mind over body." (37-9)

Punnett (pun'it) **square** A chart used to diagram the possible genotypes and phenotypes of the offspring of a cross. (8-13)

pupa (pyü'pə) The inactive stage in the life cycle of an insect that undergoes complete metamorphosis. (27-14)

pupil (pyü'pəl) The round opening in the iris of the eye. (37-18)

pyloric sphincter (pī lôr'ik sfingk'tər) A ring of muscles at the exit of the stomach; it controls the amount of food that can enter the intestine. (33-6)

R group The group of atoms that distinguishes the various amino acids. (3-21)

radial symmetry (rā'dē əl sim'ə trē) Similar parts regularly arranged about a central axis. (25-3)

radicle (rad'ə kəl) The region of a plant embryo, below the cotyledon or cotyledons, that develops into the roots. (22-3)

recessive (ri ses'iv) **trait** The genetic trait that does not appear as a phenotypic expression in a hybrid. (8-4)

regeneration (ri jen ə rā'shən) A type of asexual reproduction whereby a missing part of an organism regrows. (25-11)

releasing (ri lēs'ēng) **factors** Chemicals produced by the hypothalamus that flow down into the anterior lobe of the pituitary gland and stimulate the release of hormones. (36-2)

replication (rep lə kā'shən) Exact duplication; often used in reference to a DNA molecule. (4-5)

respiration (res pə rā'shən) All the chemical reactions in the cell that take food

molecules apart and transfer their energy to ATP. (35–1)

retina (ret'ə nə) The innermost layer of the eye; it is light-sensitive, with the expanded nerve endings of the optic nerve. (37–18)

Rh antigen An antigen found on the surface of the red blood cells of most humans (Rh-positive); can cause production of antibodies if injected into blood lacking the factor (Rh-negative). (9–12)

rhizoids (rī'zoids) Rootlike extensions of hyphae. (16–5)

rhizomes (rī' zōmz) Underground stems. (20–4)

ribonucleic (rī bō nü klē'ik) acid (RNA) A helical nucleic acid, found throughout the cell, that contains adenine, uracil, guanine, and cytosine nucleotides; present in messenger and transfer forms, both of which aid in protein formation. (4–7)

ribosome (rī'bə sōm) A particle on the surface of the endoplasmic reticulum that aids in protein manufacture. (2–12)

rods (rods) Highly modified cells of the eyes used for vision in dim light but cannot detect color. (37–18)

saliva (sə lī'və) A digestive fluid secreted into the mouth by the salivary glands. (33–2)

saprophytes (sap'rə fītz) Organisms that use dead organic matter as their source of food. (14–4)

saprozoic (sap'rə zō'ik) An organism that absorbs soluble nutrients as do saprophytic bacteria. (15–1)

savanna (sə van'ə) A tropical or subtropical grassland with scattered trees or clumps of trees and undergrowth that can resist drought. (47–9)

Schwann cells The cells that make up the myelin sheath wrapped like a jelly roll around the outside of an axon. (37–2)

sclera (sklir'ə) A tough outer layer of connective tissue that protects all the other layers of the eye. (37–18)

selectively permeable (si lek'tiv lē per'mē ə bəl) Allowing only certain sizes of molecules to pass through; permeable to small molecules and impermeable to large molecules. (2–8)

semen (sē'mən) A liquid, produced in the male reproductive system, that provides food and proper environment for a thriving sperm. (39–1)

sex-linked genes Genes on the X or Y chromosomes. (8–17)

sickle-cell anemia (sik'al sel ə nē'mē ə) A genetic disease caused by the presence of an abnormal form of hemoglobin in red blood cells; the abnormal hemoglobin has the amino acid valine instead of glutamic acid in two of the four polypeptides in the hemoglobin molecule; genetic disease named for sickle-shaped red blood cells. (3–25)

solution (sə lū'shən) A homogeneous mixture where one substance is dissolved in another. (3–12)

solvent (sol'vənt) A substance that can disperse other substances and create solutions. (3–12)

sori (sôr'ē) Clusters of sporangia that appear on the underside of mature fern leaves. (20–4)

species (spē'shēz) One or more groups of natural populations that normally interbreed to produce fertile offspring. (12–3)

spermatozoa (spēr mə tə zō'ə) Sperm; the small, motile male gametes. (39–1)

sphincter (sfingk'tər) A ring of muscles that acts as a type of valve to control the flow of material; a sphincter above the esophagus

keeps material in the stomach from coming back up the esophagus when the stomach muscles contract. (33–5)

spinal (spī'nəl) **cord** A ropelike structure that runs along the dorsal side of vertebrates; in humans, it has 31 pairs of spinal nerves that extend out from between the vertebrae. (37–7)

spindle (spin'dəl) The network of filaments to which chromosomes become attached in mitosis and meiosis. (6–7)

spiracle (spī'rə kəl) Tiny breathing holes on an insect's abdomen that are external openings of tracheal tubes. (28–13)

spirilla (spī ril'ə) Bacterial cells that take the shape of twisted rods. (14–3)

spontaneous generation (spon tā'nē əs jen ə rā'shən) The belief that life could appear from nonliving material. (2–4)

sporangiophores (spə ran'jē ə forz) Vertical hyphae that branch up from the root-like rhizoids. (16–5)

sporangium (spə ran'jē əm) A case in which spores are produced and stored for asexual reproduction. (16–3)

sporophyte (spôr'ə fit) **generation** The generation of plants that produces spores. (19–4)

spreading factor The bacterial enzyme that dissolves the substance that makes cells stick together. (17–3)

stamen (stā'mən) The male reproductive organ of a flowering plant; it produces pollen. (21–8)

sternum (stēr'nəm) Breastbone. (38–6)

stethoscope (steth'ə skōp) A medical instrument used to listen to the sound of the heart. (34–14)

stigma (stig'mə) The top of the carpel in flowering plants where pollen must land before fertilization can occur. (21–8)

stoma (stō'mə) The unit on a leaf consisting of two guard cells and a pore. (22–8)

stroma (strō'mə) The area outside the grana within the chloroplast. (5–8)

style (stīl) The slender stalk of the carpel; it supports the stigma of flowering plants. (21–8)

substrate (sub'strāt) A molecule or molecules upon which enzymes act. (5–4)

succession (sək sesh'ən) The sequence of change in number and size of plant and animal populations in a community. (44–3)

sympiosis (sim bī ō'sis) The living together of different organisms in a close relationship that may or may not be a benefit to any or all members. (42–6)

sympathetic (sim pə thet'ik) **nervous system** A division of the autonomic nervous system whose nerves produce impulses that can release energy in the case of an emergency. (37–7)

synapse (si naps') The gap between the end of one axon and the beginning of the next dendrite branch. (37–3)

syphilis (sif'ə lis) A venereal disease caused by a spiral bacterium (spirochete); signs are an open sore where the organism entered the body (usually the vagina, penis, or mouth) and swollen lymph nodes in the same area. (17–2)

system (sis'təm) A group of organs that function together to perform one or more specific functions. (1–4)

taiga (tī'gə) The swampy evergreen forest region below the tundra in North America and Eurasia. (47–5)

taxonomist (tak son'ə mist) A biologist who specializes in classifying organisms. (12–2)

telophase (tel'ə fāz) The final phase in the processes of mitosis and meiosis during which nuclear and cell divisions are completed. (6–10)

temperate phage (tem'pər it fāj) A bacteriophage that does not cause lysis of the host. (13–6)

tendons (ten'dens) Tough bands of connective tissue that attach skeletal muscles to bone. (38–13)

testes (tes'tēz) Male reproductive organs that produce sperm. (25–19)

testosterone (tes tos'tə rōn) The hormone primarily responsible for the development of the male secondary sex characteristics, including the lowering of the voice and the growth of body hair in the pubic region, underarm, and on the face. (39–2)

tetrad (tet'rad) The group of four chromatids from replicated homologous chromosomes. (6–13)

thallophytes (thal'ə fitz) Plants that grow in the form of a thallus. (16–1)

thallus (thal'əs) A plant body without roots, stems, or leaves. (16–1)

theory (thē'ər ē) Knowledge continually supported by experimental results. (1–12)

thorax (thôr'aks) In mammals, the cavity in the chest, filled mostly by the lungs. (35–3)

thylakoids (thī'lə koids) The individual disclike plates in grana. (5–8)

thymine (thī'min) A nitrogenous base that bonds with adenine in DNA. (4–3)

thyroid gland (thī'roid) A paired endocrine gland found in the neck just below the larynx; it produces the hormone thyroxine, which increases the rate of cellular respiration. (36–3)

thyroid-stimulating hormone (TSH) A hormone, from the anterior lobe of the

pituitary gland, that stimulates the thyroid gland to increase the absorption of iodine from the bloodstream and to produce and secrete its hormone. (36–3)

thyroxine (thī rok'sēn) A hormone manufactured by the thyroid gland to increase the speed of metabolism. (36–7)

tissue (tish'ü) A group of cells similar in structure and function. (1–4)

trachea (trā'kē ə) Windpipe. (34–4)

tracheae (trā'kē ē) A network of branching tubes in insects that carry oxygen directly to the cells and carbon dioxide away from the cells. (28–13)

translocation (trans lō kā'shən) The transport of food through the phloem in leaves, stems, and roots of vascular plants. (24–9)

transpiration (tran spə rā'shən) The loss of water, as water vapor, through the stomata, or pores, in the leaves of plants. (22–8, 24–3)

trichocysts (trī'kō sists) Harpoonlike structures that normally are coiled up in tiny sacs in the ectoplasm but can be discharged in defense. (15–4)

trichonosis (trik ə nō'sis) A disease caused by the presence of the trichina worm in the intestine and muscle tissue. (26–15)

tundra (tun'drə) A vast and level treeless plain that covers much of the northern part of the world. (47–4)

turgor (tër'gər) The pressure of water that keeps small plants without woody tissue rigid and upright. (24–7)

unicellular (yü nə sel'yə lər) Pertaining to a single cell. (14–1)

upwelling (up wel'ing) In an ocean, a type of water circulation that is vertical, with water flowing from the bottom upward. (46–1)

uracil (yùr'ə səl) A nitrogen base, found only in RNA, that pairs with adenine. (4-7)

urea (yu rē ə) A nitrogen by-product of protein metabolism. (35-6)

ureter (yù rē'tər) A tube through which urine flows from a kidney to the bladder. (35-9)

urethra (yù rē'thrə) A tube leading from the bladder, through which urine is released. (35-9)

urine (yùr'ən) Water that contains nitrogenous waste matter and small quantities of other substances. (35-8)

vacuole (vak'yù ōl) An enlarged cytoplasmic vessel that may contain stored water, food, or waste. (2-7)

vagina (və jī'nə) A canal in the female reproductive system that connects the uterus to the exterior. (39-1)

vas deferens (vas def'ə renz) In the male reproductive system, a tube that stores sperm and transports sperm to the seminal vesicle and the prostate gland. (39-1)

venereal (və nir'ē əl) **diseases** Diseases that are spread by contact with the genital organs. (17-1)

ventricles (ven'trə kəlz) The two lower chambers of a heart from which blood is pumped to the lungs and body. (29-12)

verification (ver ə fə kā'shən) The process of repeating an experiment to prove a hypothesis. (1-12)

vertebrae (vēr'tə brē) Bones of the spinal column of vertebrates. (38-6)

villi (vil'ī) Millions of tiny hairlike projections on the walls of the intestine; they in-

crease the inside surface area and aid absorption. (33-10)

virology (vī rol'ə jē) The study of viruses. (13-4)

virulence (vir'yə ləns) Potency. (13-5)

virulent phage (vir'yə lent fāj) A bacteriophage that causes lysis. (13-6)

virus (vī'rəs) An extremely small particle that is capable of reproduction and hereditary transmission but lacks other properties of life. (14-1)

vitamins (vī'tə mins) Chemical compounds that are essential, in small amounts, to the health and growth of organisms. (33-23)

vitreous (vit'rē əs) **humor** A fluid that fills the chamber behind the lens of the eye. (37-18)

white matter Bundles of axons and dendrites with myelin sheaths in the exterior of the spinal cord and the interior of the human brain. (37-7)

xylem (zī'lem) In plants, the vascular tissue that carries water and minerals to leaves, supports the plant, and sometimes stores food. (22-6)

zoology (zō ol'ə jē) The study of animals. (1-2)

zooplankton (zō ə plangk'tən) Animal-like plankton; consumers, many of which feed on the phytoplankton. (45-3)

zygospore (zī'gə spôr) A zygote with a tough outer shell. (16-5)

zygote (zī'gōt) The new cell or individual, that results from the fusion of egg and sperm in sexually reproducing organisms. (21-10)

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